June 89

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories
Laboratoires de recherche minière

THE EXPLOSIBILITY OF THREE CANADIAN COAL DUSTS

K.J. Mintz

MRL 89-50(TR)

Canada

[redacted]

THE EXPLOSIBILITY OF THREE CANADIAN COAL DUSTS

K.J. Mintz

MRL 89-50(TR)

April 1989

Work carried out under the PERD program

THE EXPLOSIBILITY OF THREE CANADIAN COAL DUSTS

by

K.J. Mintz*

ABSTRACT

Explosibility measurements on coal dusts from the Cape Breton Development Corporation's Lingan Mine, TransAlta's Highvale Mine and the Quintette Mine in B.C. have been carried out along with some tests on Pittsburgh Standard coal dust. The Quintette coal dust would not explode in the classical Hartmann apparatus, but did explode in the new 20-L vessel using a more powerful ignition source. The minimum explosible concentrations of the Lingan, Highvale and Pittsburgh coal dusts were all about the same (40 - 45 mg/L), that of the Quintette was higher (140 mg/L). The difference may be attributed to the much greater mean particle size of the Quintette dust. The explosion pressures (in kPa) were: Highvale, 600, Pittsburgh, 520, Lingan, 510, and Quintette, 440. The minimum oxygen concentrations required for explosions were (in % oxygen): Highvale 10.4, Lingan 10.5, and Quintette 14. The minimum ignition temperatures of dust clouds were (in °C): Highvale 510, Lingan 600, Quintette 620 and Pittsburgh 620. Further work is required to reconcile limit values.

---

*Research Scientist, Canadian Explosive Atmospheres Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa

KEYWORDS: dust explosions, coal

EXPLOSIBILITE DE TROIS POUSSIERES DE CHARBON CANADIENNES

par

K.J. Mintz*

RESUME

Des mesures d'explosibilité ont été effectuées sur des poussières de charbon de la mine Lingan de la Société de développement du Cap-Breton, de la mine Highvale de TransAlta et de la mine Quintette en Colombie-Brittanique, ainsi que les essais sur une poussière de charbon de Pittsburgh Standard. La poussière de charbon de Quintette n'a pas explosé dans l'appareil classique de Hartmann, mais l'a fait dans la nouvelle enceinte de 20 L munie d'une source d'allumage plus puissante. Les concentrations explosible minimales des poussières de charbon de Lingan, Highvale et Pittsburgh étaient toutes voisines (40-45 mg/L), et celle de Quintette était plus élevée (140 mg/L). La différence est attribuable au diamètre moyen beaucoup plus élevée des particules de la poussière de Quintette. Les pressions d'explosion (en kPa) étaient: Highvale 600, Pittsburgh 520, Lingan 510 et Quintette 440. Les concentrations minimales d'oxygène nécessaires aux explosions étaient (en % oxygène): Highvale 10,4, Lingan 10,5 et Quintette 14. Les températures minimales d'allumage des nuages de poussières étaient (en °C): Highvale 510, Lingan 600, Quintette 620 et Pittsburgh 620. D'autres travaux s'imposent pour concilier les valeurs limites.

---

*Chercheur scientifique, Laboratoire canadien des atmosphères explosives, Laboratoires de recherche minière, CANMET, Energie, Mines et Ressources Canada, Ottawa

MOTS CLES: explosions de poussière, charbon

TABLE OF CONTENTS

TABLE

FIGURES

FIGURES (cont'd)

INTRODUCTION

Coal dust has been known to be involved in explosions in underground mines since the nineteenth century. Despite all the preventative measures that have been developed since then, dust explosions causing major loss of life in underground mines continue to occur occasionally. Coal handling facilities above ground can also experience coal dust explosions; the outcome of such explosions usually are not as significant in terms of loss of life, but can be significant in terms of property damage. Research continues throughout the world on the causes of and remedial action for coal dust explosions, as shown by the majority of papers in a recent symposium on industrial explosions (1) and a number of papers presented to the biannual International Conference of Mine Safety Research Institutes (2).

CANMET has been carrying out explosibility tests on Canadian coal dusts since 1979 (3). The results indicated that the coals ranged from being non-explosible to more explosible than Pittsburgh standard coal dust. CANMET has also awarded contracts to McGill University to carry out fundamental studies on dust explosions, with emphasis on coal (4,5,6).

In 1987, arrangements were made to obtain samples of coal dust from mines in three different provinces: the Cape Breton Development Corporation (CBDC) Lingan Mine, TransAlta's Highvale Mine in Alberta, and the Quintette Mine in B.C. These representative samples were for use by McGill University as part of their contract and for in-house tests. In addition, the U.S. Bureau of Mines sent a sample of Pittsburgh standard coal dust. Preliminary tests were carried out in the classical Hartmann apparatus at CEAL in early 1988, but the major part of the work was delayed until 1989, after the 20-L vessel had been commissioned.

The Interdepartmental Panel on Energy R/D provided funds for this laboratory's work on coal dust explosions in FY87/88 and FY88/89. The funding was used for external contracts, commissioning of dust explosion equipment in-house and the study presented in this report.

EXPERIMENTAL SECTION

Coal dust samples

Pittsburgh standard coal dust is bituminous coal dust of composition 36% volatiles, 56% fixed carbon, 2% moisture and 6% ash. The dust had been screened by the USBM through 200 mesh to give a particle size of less than 75 μm (8). No further processing was carried out.

The CBDC coal dust originated from the 10E wall - Harbour Seam of the Lingan Mine. It was crushed and passed through a 325 mesh screen (45 μm) by the Coal Research Laboratory (CANMET), Sydney, N.S. No further processing was carried out.

The Quintette Coal Ltd. (Tumbler Ridge, B.C.) sent a sample of "fine coal dust collected at the Overland Conveyor Bunker Station". The interest in this coal was that it was reported to "act like a fluid", possibly having higher-than-expected explosibility characteristics. The sample was tested "as is".

A sample of coal lumps from TransAlta's Highvale Mine was sent by the Coal Research Laboratory (CANMET), Devon, Alta. The lumps were ground and sieved through 325 mesh and used within 3 days after grinding. Its composition was 29% volatiles, 40% fixed carbon, 17% moisture and 14% ash.

Apparatus

The Hartmann apparatus is the classical apparatus for measuring the maximum explosion pressure and rate of pressure rise and forms the basis for the ASTM Standard for these measurements (9). CANMET has had a copy of this apparatus for a number of years; it was rebuilt recently to conform to the Standard (10). The apparatus consists of a tube 70 mm diameter and 300 mm long, into which the sample of dust is placed. A short burst of air is used to disperse the dust. A continuous electrical discharge acts as the igniting source. The pressure is measured by a transducer installed on the top of the tube.

The Hartmann apparatus has fallen into disfavour on several accounts. Striking the discharge before the dust dispersion occurs means that there will not be a uniform distribution of dust at the time of ignition. The diameter of the tube is considered to be too small. The discharge does not supply enough energy to ignite dusts which are known to ignite in industrial situations. Moreover, the test is actually carried out above atmospheric pressure, because of the added air used for dispersion.

To overcome these deficiencies, larger vessels have been designed; prominent among these is the USBM 20-L vessel (11), of which we have a copy. This apparatus has recently been commissioned (12) and is now used regularly for explosion testing.

The Godbert-Greenwald furnace was used for determining the minimum ignition temperature (MIT) of the dust clouds. It consists of a vertical tubular furnace, the top of which is connected to a dust sample holder and air chamber. A pulse of air entrains the dust and pushes it through the furnace. Flames emitted from the bottom of the furnace indicate that the furnace temperature is above the MIT. Details of our apparatus are given elsewhere (13).

Procedure

In all the explosion tests with the 20-L vessel, the weighed dust sample was placed into the sample holder at the base of the vessel, then the ignitor connected, and finally the vessel completely evacuated. The 16-L air chamber was filled with gas to 1100 kPa pressure and the trigger to start the test was pressed. The solenoid opened for a preset time which allowed the gas to flow through the dust chamber forming a dust cloud in the 20-L vessel. After a preset time, the ignitor was fired. The entire pressure history of the test was captured on a digital oscilloscope. A thermocouple located near the wall of the vessel provided an indication of the relative intensity of the explosion (if one occurred), though it should be emphasized that it did not indicate the true flame temperature. After the combustion gases had cooled, they were passed through an oxygen analyzer, from which the percentage of oxygen consumed was calculated.

All of the explosion tests were carried out at about one atmosphere pressure (101.2 kPa). Because of unavoidable variabilities, the pressure at the time of ignition could vary by up to 5 kPa. It is known that the explosion pressure is directly proportional to the pressure at the time of ignition. Therefore, a small correction was made to the experimentally determined explosion pressure so that it represents the value for 101.2 kPa.

Figure 1 shows the pressure trace of a test carried out at the optimum concentration of CBDC coal dust. The initial pressure is 0 kPa (absolute). The ramp was due to the entry of the air into the vessel. The pressure then remained constant (at about one atmosphere) for a short period before the electrical arc was fired, after which the pressure rose quickly.

The maximum on this trace yields the explosion pressure. Afterwards, the post-combustion gases cooled, resulting in the relatively slow pressure decrease.

As has already been mentioned, a stronger ignitor than an electrical arc is needed for some dusts. A 5-kJ chemical ignitor, manufactured by Sobbe, was used for many of these tests. The solid line in Fig. 2 shows the pressure trace of a test with the same dust and under the same conditions as that used for Fig. 1, but using the Sobbe ignitor in place of the arc. The general appearance of the trace is similar, but the peak is sharper and the ignition point more sharply defined. The broken curve in Fig. 2 is the trace of the temperature, which started to rise shortly after the ignition point, and continued to rise for several seconds before decreasing slowly.

A 16-fold expansion along the time axis of the pressure trace shows that the pressure peak has an irregularity (see solid line in Fig. 3). This was due to the pressure from the ignitor. The lower broken line in Fig. 3 shows the pressure trace generated when only the Sobbe ignitor was fired. The pressure that can be actually attributed to the explosion of the dust is then the difference between these two curves, shown as the upper broken curve. The explosion pressure is thus the maximum of the last curve. The maximum rate of pressure rise was also determined from this curve. All these operations are carried out quickly and easily on the digital oscilloscope.

The maximum explosion pressure is determined by varying the concentration of dust until the highest explosion pressure is found. Since the plot of explosion pressure versus concentration is very broad, this procedure causes little difficulty and a precision of better than 10% is expected. The maximum rate of pressure rise is more dependent on various conditions and, as will be seen by the ignitor; thus, its precision is much lower. For marginal explosions, in which the explosion pressure is less than the pressure due to the Sobbe ignitor, the subtraction procedure yields an imprecise value for the maximum rate of pressure rise. The measurement of the minimum explosible concentration (MEC) is not as straightforward as might be expected. It is necessary to use the Sobbe ignitors for that measurement in order to obtain meaningful results.

The minimum oxygen concentration (MOC) is the lowest percentage of oxygen in the 20-L "atmosphere" that will allow an explosion to occur. To carry out tests to determine this parameter, mixtures of air and nitrogen are made up in the 16-L air chamber; the actual oxygen concentration is verified using the oxygen analyzer. The optimum concentration for producing the maximum explosion pressure is used in this series of tests.

The MIT is determined by starting at a temperature at which good ignitions occur, then conducting tests at successively lower temperatures until no ignitions are obtained. At that point, the conditions of the test are varied in order to try to obtain ignitions. If so, the temperature is decreased again. Finally, four successive non-ignitions must be obtained to obtain the MIT.

RESULTS

CBDC Lingan Mine Coal Dust

Figure 4 shows the explosion pressure as a function of concentration; the circles are tests carried out using the Sobbe ignitor, the squares, with an electric arc. As can be seen, the explosion pressure is virtually constant at the higher concentrations. Pressures from the arc and chemical ignitor tests appear to agree at the higher pressures. At 500 mg/L, the arc produced a lower pressure, probably because at that concentration, the arc energy was close to the minimum ignition energy.

Six tests were carried out at the same concentration (1000 mg/L) using the arc in order to measure the reproducibility. The mean was 527 kPa and the standard deviation was 14 kPa (2.7%).

Tests carried out in the Hartmann chamber yielded a maximum pressure of 655 ± 41 kPa at the same concentration, about 25% higher than the values obtained in the 20-L vessel. However, as mentioned above, in the Hartmann tests, ignition actually occurred at an elevated pressure and the experimental explosion pressure must be reduced proportionately to yield the value for one atmosphere. For Lingan coal dust, the corrected explosion pressure is 473 ± 30 kPa, slightly lower than the 20-L value. Feng (3) measured the explosion pressure as 850 kPa using the Hartmann apparatus, much higher than the values obtained here. In the compilation by Field (14), the maximum explosion pressure of coal using the Hartmann apparatus was 640 kPa; in the USBM compilation (15), the maximum was 710 kPa.

Figure 5 shows $(dP/dt)_{max}$ for both the Sobbe and the arc ignitor. For this parameter, the latter produced a much lower rate of pressure rise. Furthermore, the scatter was much greater: at 1000 mg/L, the mean value was 6.9 Mpa/s, the standard deviation was 1.2 MPa/s (17%). The reason is that this parameter is much more sensitive to the size of the ignition source; with the arc, it takes some time for the full explosion to develop.

$(dP/dt)_m$ is known to decrease significantly with the volume of test vessel; Bartknecht devised a parameter,

$$K_{st} = (dP/dt)_m \cdot (\text{Volume})^{1/3},$$

which is volume-independent. The 20-L tests yielded K_{st} values of 27 (Sobbe) and 19 (arc), and the Hartmann tests yielded 22 MPa·m/s. Feng (3) obtained a K_{St} of 6.5 MPa·m/s.

The percentage consumption of oxygen indicates how complete the reaction is. Figure 6 shows that above about 200 mg/L for tests carried out with the Sobbe ignitor, essentially all the oxygen reacts. The shape and position of this curve is similar to that of the explosion pressure curve (Fig. 4). All the arc tests for which oxygen consumption was measured yielded essentially complete reactions.

The maximum temperature rise as a result of the explosion is shown in Fig. 7 for the same set of tests. Above about 200 mg/L, the temperature seems to be constant. The arc tests appear to yield slightly higher values; the reason for this is unknown.

To determine the minimum explosible concentration (MEC), it is necessary to expand the lower part of the explosion pressure-concentration curve to produce Fig. 8. Cashdollar and Hertzberg (11) define the lower flammability limit (another term for the MEC) as that concentration giving a pressure ratio of 2 (equivalent to an explosion pressure of 101 kPa gauge in our system). From Fig. 8, the MEC (Cashdollar-Hertzberg criterion) would be 45 mg/L. Knystautas and Lee (7), on the other hand, define the MEC as that concentration at which the slope of the curve changes. This occurs usually at a lower pressure than 101 kPa and therefore, the resultant MEC is smaller. Using the same sample of Lingan coal dust, but testing in a much larger vessel (180 L) with black powder as the ignitor, they obtained 40 mg/L, for a delay time between dispersion and ignition of 100 ms, and 50 mg/L, for a delay time of 200 ms. Figure 8, using the Knystautas-Lee criterion, yields 40 mg/L for the MEC. (The delay time in our experiments was about 120 ms.) The agreement is excellent, particularly considering the differences between the apparatuses.

The MOC for the Lingan mine dust was determined from the pressure-oxygen concentration curve (Fig. 9) to be 10.5%. This value is corroborated by the oxygen consumption and temperature rise graphs (Figs. 10 and 11).

TransAlta's Highvale Mine Coal Dust

Figures 12 - 14 show the results of tests carried out on this sample at various concentrations. (The dimensions of the axes of these graphs are the same as those of the other coal dusts to allow easy comparison.) Fewer tests were carried out than for the Lingan coal dust, and none with the arc ignitor, because of time limitations. Nevertheless, reasonably precise measurements of the maximum explosion pressure and MEC were made. The MEC is the same within experimental uncertainty as the Lingan dust; the maximum explosion pressure is slightly higher.

Figures 15 and 16 show that explosions of this sample have a sharp cut-off as the oxygen concentration is reduced; hence, the MOC could be determined very precisely. The value of 10.4% is close to the MOC of Lingan (10.5%).

Quintette Mine Coal Dust

A number of tests were carried out in the Hartmann apparatus at concentrations of up to 2000 mg/L. There was no evidence of reaction, either by a pressure rise or by a change in the appearance of the dust. Hence, the first impression was that this coal dust was non-explosible.

Explosibility tests in the 20-L chamber using the 5-kJ Sobbe ignitor showed that this dust was explosible. Figure 17 shows that the maximum explosion pressure was about 440 kPa, somewhat lower than the other coals.

The same graph was used to determine the MEC. The Knystautas-Lee criterion yielded 140 mg/L; the Cashdollar-Hertzberg criterion yielded 165 mg/L. Knystautas and Lee measured the MEC of the same sample of dust in their 180-L vessel and obtained a value of 150 mg/L, in good agreement with our value. The pressure-concentration and the $(dP/dt)_m$ curves (Figs. 17 and 18, respectively), rise much less steeply than the corresponding curves of the other coal dusts, but more rapidly than the curves of Knystautas and Lee. The oxygen consumption and temperature rise curves (Figs. 19 and 20, respectively) confirm that the dust is explosible and are consistent with the value of the MEC. The oxygen consumption curve rises steeply; perhaps this indicates that burning of the coal dust occurred after the explosion.

Three tests using the arc ignitor and a concentration of 1000 mg/L produced no evidence of reaction. Hence, the "nonexplosibility" of the Quintette coal dust observed in the Hartmann apparatus tests was due to the inadequacy of the arc ignitor.

Figure 21 does not define the MOC very sharply; it is about 14.0%. The oxygen consumption and temperature rise curves (Figs. 22 and 23, respectively) also have considerable scatter. Perhaps, the scatter is due to the use of "as is" material, rather than screened. Interestingly, the MOC derived from Fig. 22 and 23 is only about 13.0%, significantly lower than the MOC from the explosion pressure curve. Perhaps, this lower value is also due to burning of the dust after the explosion has occurred.

Pittsburgh Standard Coal Dust

Figure 24 shows the pressure-concentration dependence of this dust. The maximum explosion pressure was about 520 kPa, which is slightly lower than the USBM's value of about 570 kPa (16). The one test carried out with the arc ignitor yielded a similar explosion pressure.

Explosion tests in the Hartmann apparatus yielded a maximum explosion pressure of about 550 kPa, slightly lower than the value of 600 kPa measured by Feng (3) and 620 kPa measured by the USBM (17).

Figure 25 shows the experimental data for $(dP/dt)_m$ from the 20-L vessel. The large scatter makes it difficult to make comparisons, except that it appears that the maximum value is probably greater than the USBM's value of 11 Mpa/s (16). The Hartmann tests yielded somewhat lower values of $(dP/dt)_m$ than those in the literature: 10 MPa/s vs. 12 MPa/s (Feng, 3) and 16 MPa/s (USBM, 17).

From Fig. 24, the MEC was determined to be 45 mg/L, significantly lower than the 90 mg/L measured by Cashdollar et al (16). Examination of their actual experimental results of explosion pressures (their Fig. 5) indicates that there is not much discrepancy for the same strength of ignitor, but that the difference occurs because of the criteria used for the MEC. Earlier work by the USBM in their 8-L vessel yielded an MEC of 123 - 145 mg/L (18). The oxygen consumption curve (Fig. 26) and the temperature rise curve (Fig. 27) are consistent with the explosion pressure curve.

Minimum Ignition Temperature (MIT)

The MIT of the standard Pittsburgh coal dust was measured as 620°C, which agrees well with the USBM value (using the same type of apparatus) of 610°C (17). Feng (3) obtained an MIT of 500°C, which would appear to be much too low. Recently, the USBM have obtained a value of 540°C using an improved apparatus, the 1.2-L vessel (16).

The MIT of the Lingan coal dust was measured as 600°C, again much higher than the 480°C measured by Feng (3).

The MIT of the Quintette mine coal dust was 620°C. To determine if particle size affected these results, a sample of this coal dust was screened through 400 mesh (38 μm). The MIT was exactly the same; the only difference was that there was a sharper cut-off between ignition and non-ignition.

The Highvale Mine coal dust yielded the lowest value of MIT: 510°C. Since this test was carried out on freshly ground dust, a second determination was carried out a week later on the same sample to determine if aging affected the result. The MIT was then 500°C; the difference is within the experimental uncertainty.

Particle Size Analysis

Because the explosibility of dust is known to be a strong function of particle size, it is important to know the distribution of the particle size of the samples tested. A shaker using a range of sieves of different size of openings is often used for this purpose. The smallest opening available is 38 μm (400 mesh). The coal dusts in this study were very fine, hence, it was necessary to use another method. The Quantimet 720 image analyzer has recently been re-commissioned in the dust laboratory, primarily for size analysis. The method of using this instrument will be detailed in a forthcoming report.

Figure 28 shows the distribution of the Lingan, Highvale and Quintette coal dusts. The Quintette dust was used "as received"; it is clearly much coarser than the other two dusts. Perhaps its lower explosibility can at least be partly explained on that basis. Both the other two dust samples were prepared by grinding and then sieving through a 45 μm (325 mesh) screen. The particle size distributions were not identical: the

Highvale sample was slightly finer (a mean particle size on a mass-weighted basis of 23 μm vs. 29μm). Hertzberg and Cashdollar (19) have shown that the MEC becomes independent of particle size below a certain value depending on the dust. For two different coals, they found values of 15 and 35 microns. Hence, the difference in particle size between the Lingan and Highvale samples probably did not affect the explosibility significantly. The Pittsburgh standard coal dust had been screened through 75 μm (200 mesh); therefore, its particle size distribution curve would lie between that of Quintette and Lingan.

DISCUSSION

All the coal dusts tested were explosible. The results of all the tests are summarized in Table 1. The uncertainty quoted is either the standard deviation calculated from repetitive tests or is the best estimate of the precision from a graph.

The Quintette coal dust has a much higher minimum ignition energy than the other coal dusts, as shown by not being initiated by the electric arc, either in the Hartmann apparatus or the 20-L vessel. In practice, many sources of ignition have much greater energies than this arc. Hence, the additional margin of safety created by the higher minimum ignition energy for this dust may not be too important, except possibly for some electrical equipment. In addition, it has not been proven that the Quintette dust is intrinsically safer than the other dusts. At least part of its lower explosibility is due to the Quintette dust having a much larger mean particle size. If, in part of the operation, the particle size is reduced (through e.g. abrasion), then the hazard will probably be higher.

The MIT is a measure of the hazard of hot surfaces igniting a dust. Lingan, Quintette and Pittsburgh all have about the same MIT. One might be surprised that the Quintette coal dust is similar, considering that it is much less explosible in the other tests. However, the Quintette sample did contain fines; the methodology of the Godbert-Greenwald apparatus is such that only the most sensitive fraction (in this case, the fines) is important. The Highvale coal dust had a significantly lower MIT than the other dusts; the only possible explanation, apart from being intrinsically more sensitive, is that long-term surface oxidation, or some other aging process, after grinding is important.

The good agreement with Knystautas and Lee (7) for the values of the MEC of Lingan and Highvale coal dusts is encouraging. Conversely, the poor agreement with the USBM on the MEC of Pittsburgh standard coal dust (45 vs. 90 mg/L) is disquieting. Our earlier tests on lycopodium also yielded a much lower MEC than the USBM (30 vs. 55 mg/L (20)), but was in close agreement with Bartknecht's value of 32 mg/L (21). The answer to these discrepancies may lie in the criteria used for determining the limit values, in Hertzberg's terminology (18), "hard" vs. "soft".

Hertzberg and Cashdollar (19) obtained 14% for the MOC of Pittsburgh standard coal dust, which is significantly higher than the values obtained here for Lingan and Highvale coal dusts. The only reasonable source of error that could produce too low a value for the MOC would be an error in the gas mixture used. Great care was taken in this respect. A sample from the gas mixture in the air tank was passed through the oxygen analyzer (which was calibrated frequently) before and after the explosion test. The value obtained agreed well (within 0.2%) with the value calculated on the basis of partial pressures of nitrogen and air used to prepare the mixture in the air tank. Recall that the 20-L vessel was evacuated before the test; the leak rate into the vessel was measured occasionally to show that there was essentially no leakage in the time frame of the experiment. It is possible that the cause of the difference is the different criteria used for the limit value, as was the case for the MEC.

CONCLUSIONS

The use of the Hartmann apparatus or the use of an electric arc ignitor in the 20-L vessel can lead to the false conclusion that a particular dust is not explosible when in fact it is, the case in point being the Quintette coal dust. Although this dust does have a substantially higher MEC than the other coal dusts studied, as well as a lower explosion pressure, K_{st} and minimum ignition energy (i.e., it is less explosible according to all parameters except for MIT), nevertheless, it must be treated as an explosible dust. The difference in explosibility may, in part, be due to the difference in particle size.

The discrepancy in the MEC and MOC values between the USBM values and ours is a matter of some concern and should be studied further. Some of the difference may be due to the different criteria used for determining the limit values. Experimental data can be used for defining a "safe" concentration of dust in the air and for determining inerting requirements; therefore, it is important that the data be fully justified.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. G. Bonnell of the Coal Research Laboratories, Sydney, N.S., for obtaining and preparing the Lingan Mine coal dust, Mr. M. Sapko of the USBM for sending the sample of Pittsburgh standard coal dust, Mr. D. Turner, of the B.C. Mines Inspectorate for arranging for the shipment of coal dust from the Quintette Mine and Mr. K. Kar, of the Coal Research Laboratories, Devon, Alta., for sending the sample from the Highvale Mine. Mr. K. Judge carried out the image analysis tests.

REFERENCES

1. Cashdollar,K.L. and Hertzberg, M. (ed.) "Industrial Dust Explosions", ASTM Special Technical Publication 958, American Society for Testing and Materials, Philadelphia, Pa.; 1986.
2. Green, A.R. "Safety in Mines Research", A.A. Balkema, Rotterdam; 1985.
3. Feng, K.K. "Hazardous characteristics of Canadian coal dusts", published by the XXth International Safety in Mines Research Conference, Sheffield, U.K.; 1983.
4. Lee, J.H.S. et al "Development of equipment and techniques to evaluate boundary effects of methane coal dust explosion", Contract Report No. OSV82-00039; 1984.
5. Lee, J.H.S. "Influence of turbulence on dust explosions and the effect of methane on coal dust-air explosions", Contract Report OST85-00119; 1985.
6. Lee, J.H.S. et al "Determination of turbulence effects on the severity of dust explosions", Contract Report No. OST84-00347; 1986.
7. Knystautas R. and Lee, J.H. "Flammability limits and quenching of dust-air flames", Contract Report No. 23440-7-9045; 1988.
8. U.S. Bureau of Mines, Material Safety Data Sheet; 1987.
9. ASTM Standard E789-81 "Pressure and rate of pressure rise for dust explosions in a closed vessel", American Society for Testing and Materials; 1981.
10. Mintz, K.J. "Dust explosibility tests: Hartmann apparatus"; Division Report MRL 87-138 (TR), 1987.
11. Cashdollar, K.L. and Hertzberg, M., Rev. Sci. Instrum. 56, 596; 1985.
12. Mintz, K.J. "Commissioning of the 20-L vessel for studying dust-air explosions"; Division Report MRL 88-32 (TR), 1988.

13. Mintz, K.J. and Judge, K.J. "Commissioning and use of the minimum ignition temperature apparatus for dusts"; Division Report MRL 88-55 (TR), 1988.

14. Field, P. "Dust explosions", Elsevier, Amsterdam; 1982.

15. Nagy, J., Dorsett, H.G. and Cooper, A.R. "Explosibility of carbonaceous dusts", USBM RI6597; 1965.

16. Cashdollar, K. et al "Laboratory and mine dust explosion research at the Bureau of Mines", in "Industrial Dust Explosions" pp.107-123, ASTM, Philadelphia;1987.

17. Nagy, J. et al "Explosibility of carbonaceous dusts", USBM RI6597; 1965.

18. Hertzberg, M. et al "The flammability of coal dust-air mixtures", USBM RI 8360;1979.

19. Hertzberg, M. and Cashdollar, K. "Introduction to dust explosions" in "Industrial Dust Explosions pp.5-32, ASTM; 1987.

20. Kubal,T.A., Perzak, F.J. and Litchfield, E.L. "Electrical ignition of lycopodium in a modified Hartmann apparatus", USBM RI 8600; 1981.

21. Bartknecht, W. "Preventive and design measures for protection against dust explosions", in "Industrial Dust Explosions: ASTM, Philadelphia; 1987.

Table 1. Summary of Explosibility Measurements on Coal Dusts

	Lingan	Highvale	Quintette	Pittsburgh
P_m (kPa)				
Sobbe	510 ± 20	600 ± 20	440 ± 20	520 ± 20
arc	527 ± 14	n.d.	0	540
K_{st} (bar·m/s)				
Sobbe	27	50 ± 10	14	40 ± 10
arc	19	n.d.	0	21
MEC (mg/L)	40 ± 5	45 ± 5	140 ± 20	45 ± 5
MOC (% O_2)	10.5 ± .2	10.4 ± .1	14 ± .5	n.d.
MIT (°C)	600 ± 10	510 ± 10	620 ± 10	620 ± 10

Note: n.d. means not determined

FIG.1 PRESSURE TRACE - ARC

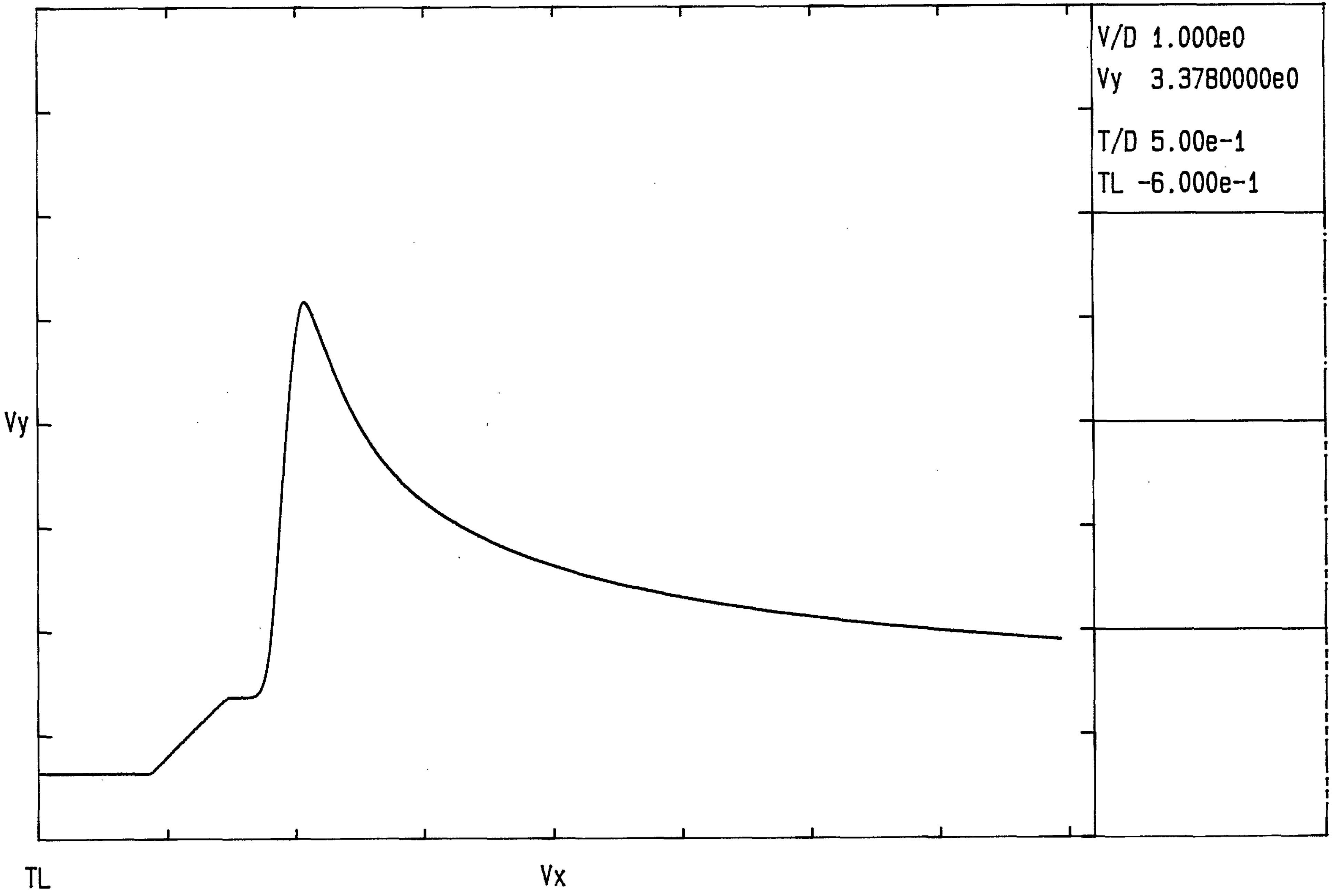


FIG.2 PRESSURE/TEMP.: SOBBE IGN.

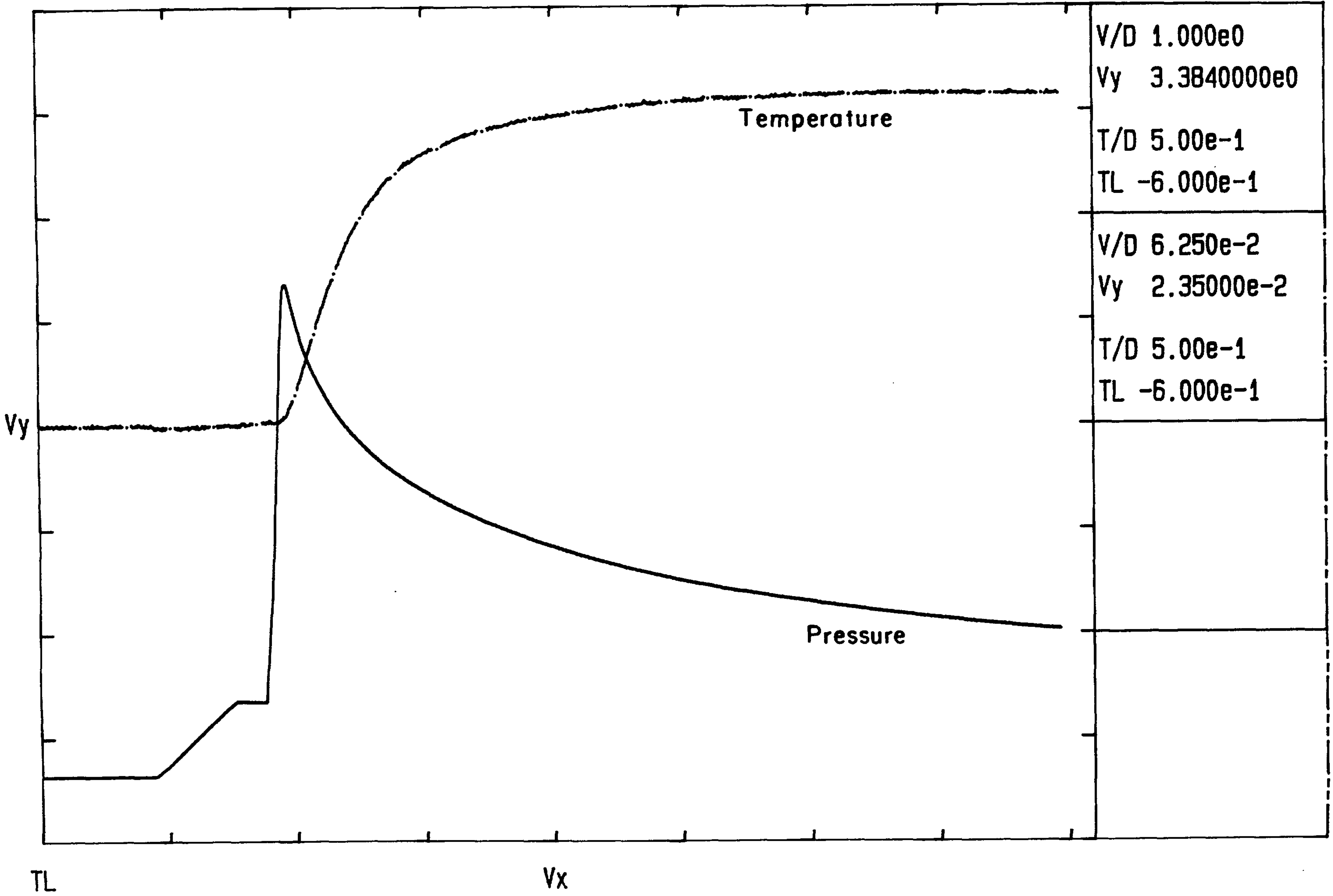


FIG.3 GENERATION OF EXPL. PRESS.

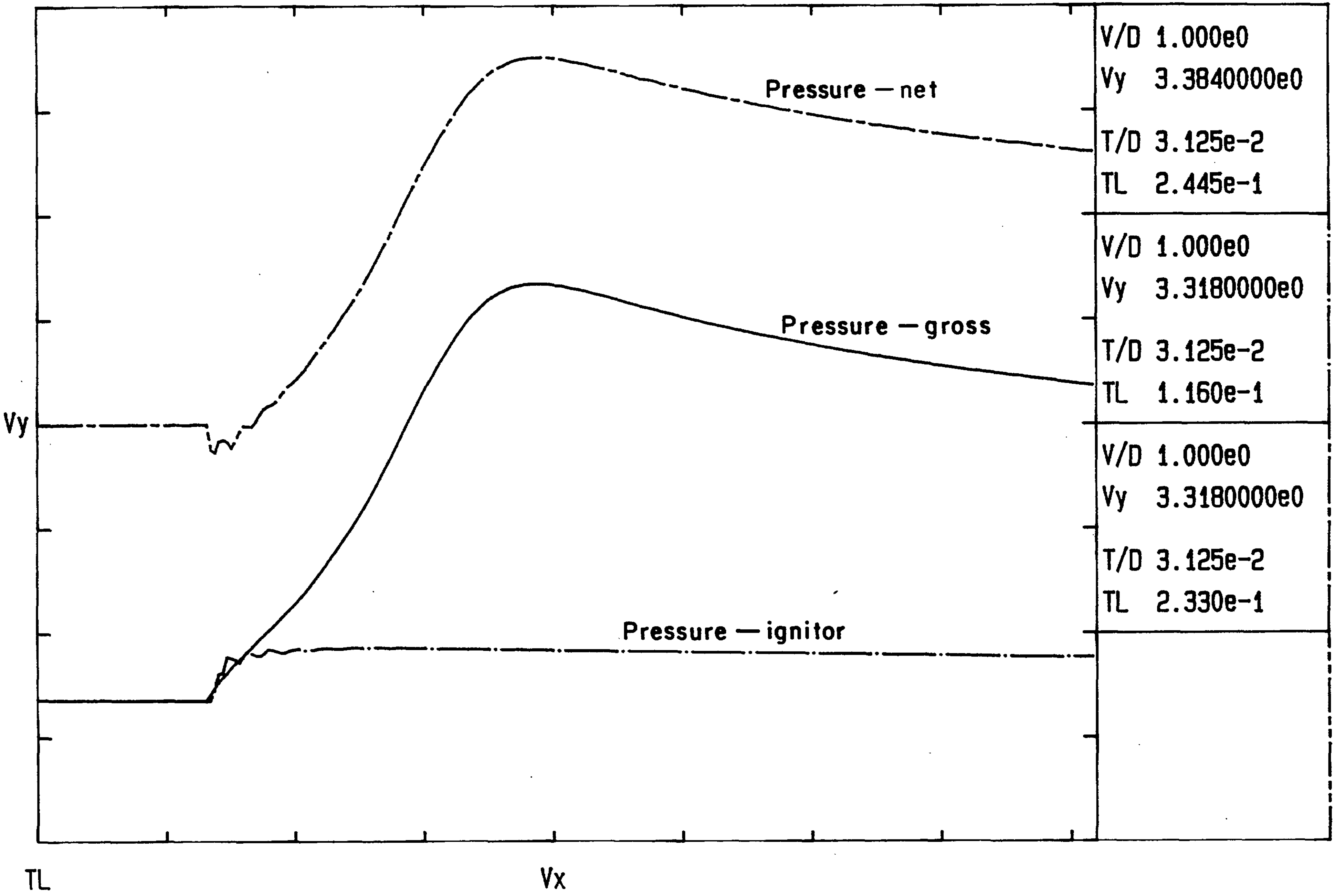


Fig.4.Lingan Mine Coal Dust: Max. Pressure

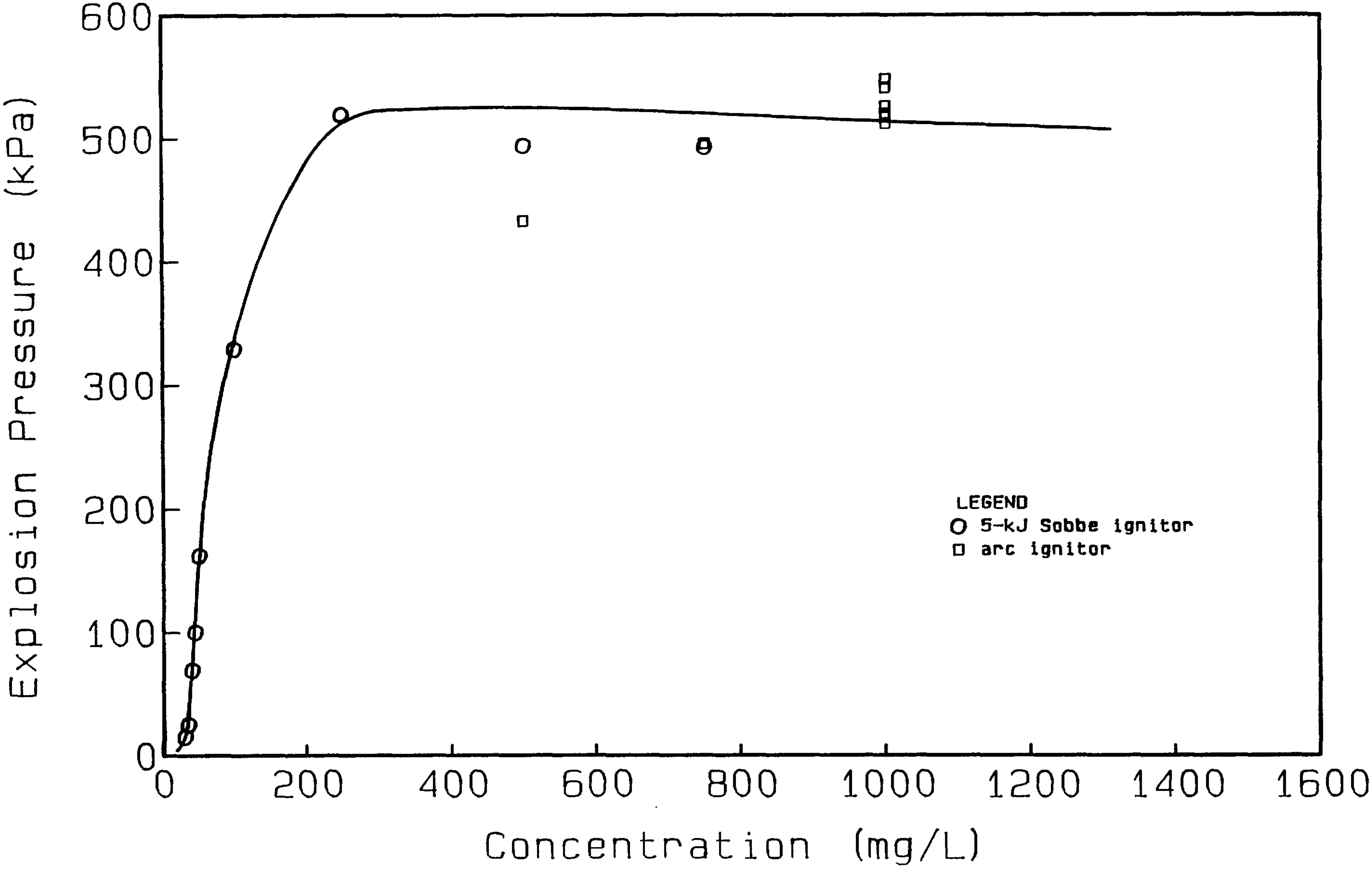


Fig.5.Lingan Mine Coal Dust: (dP/dt) - max.

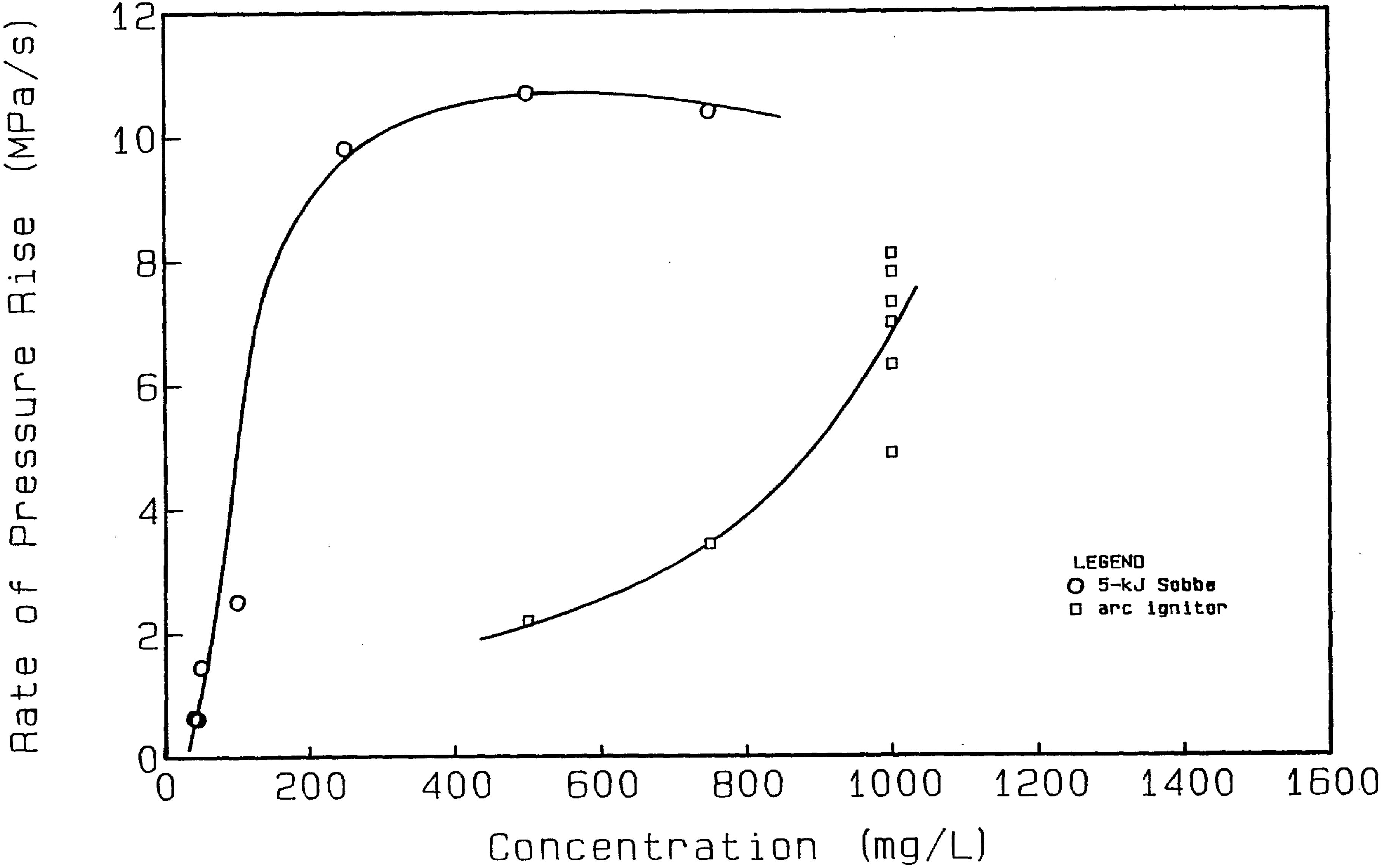


Fig.6.Lingan Mine Coal Dust: oxygen consumed

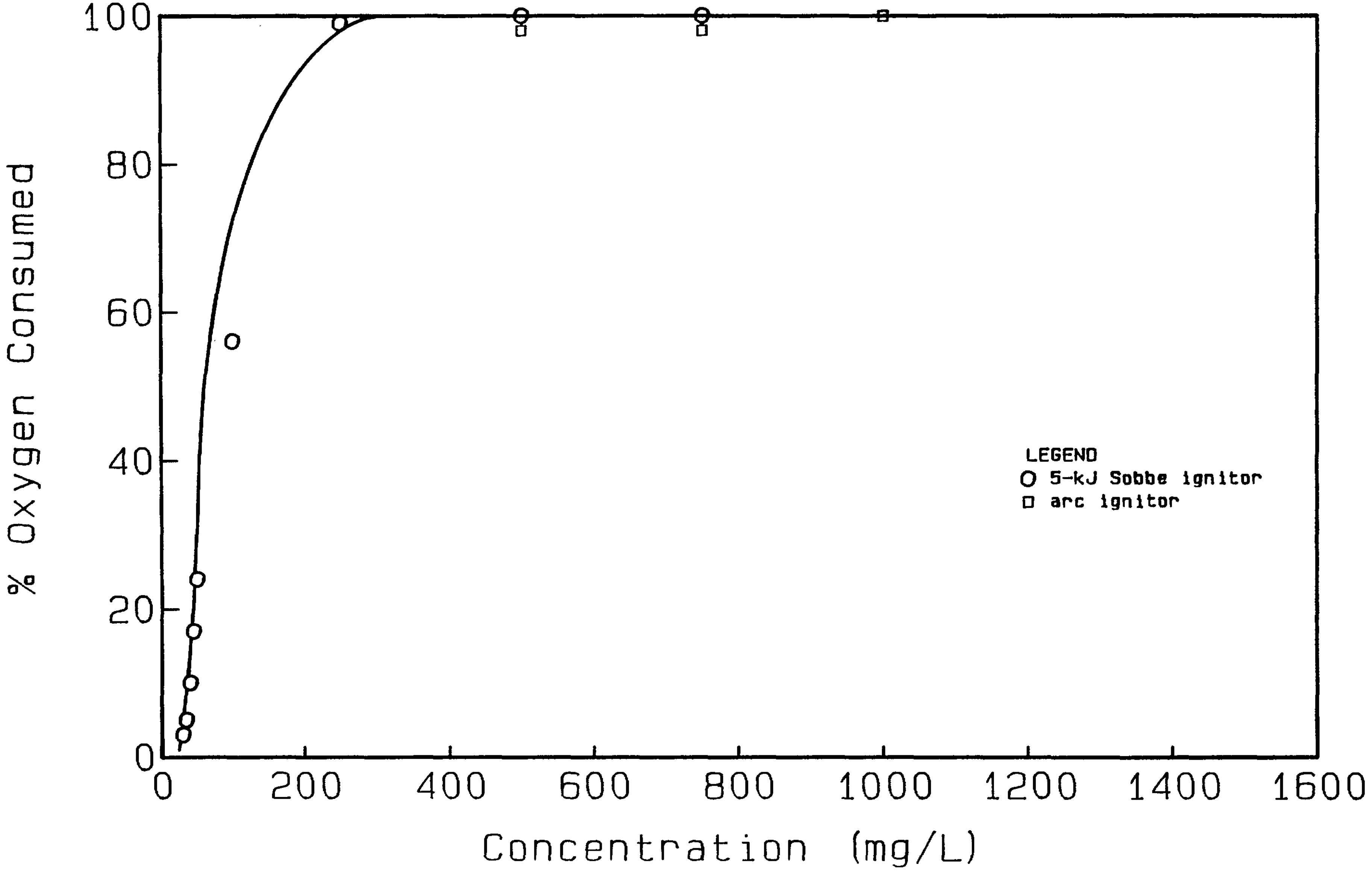


Fig.7.Lingan Mine Coal Dust: Temperature

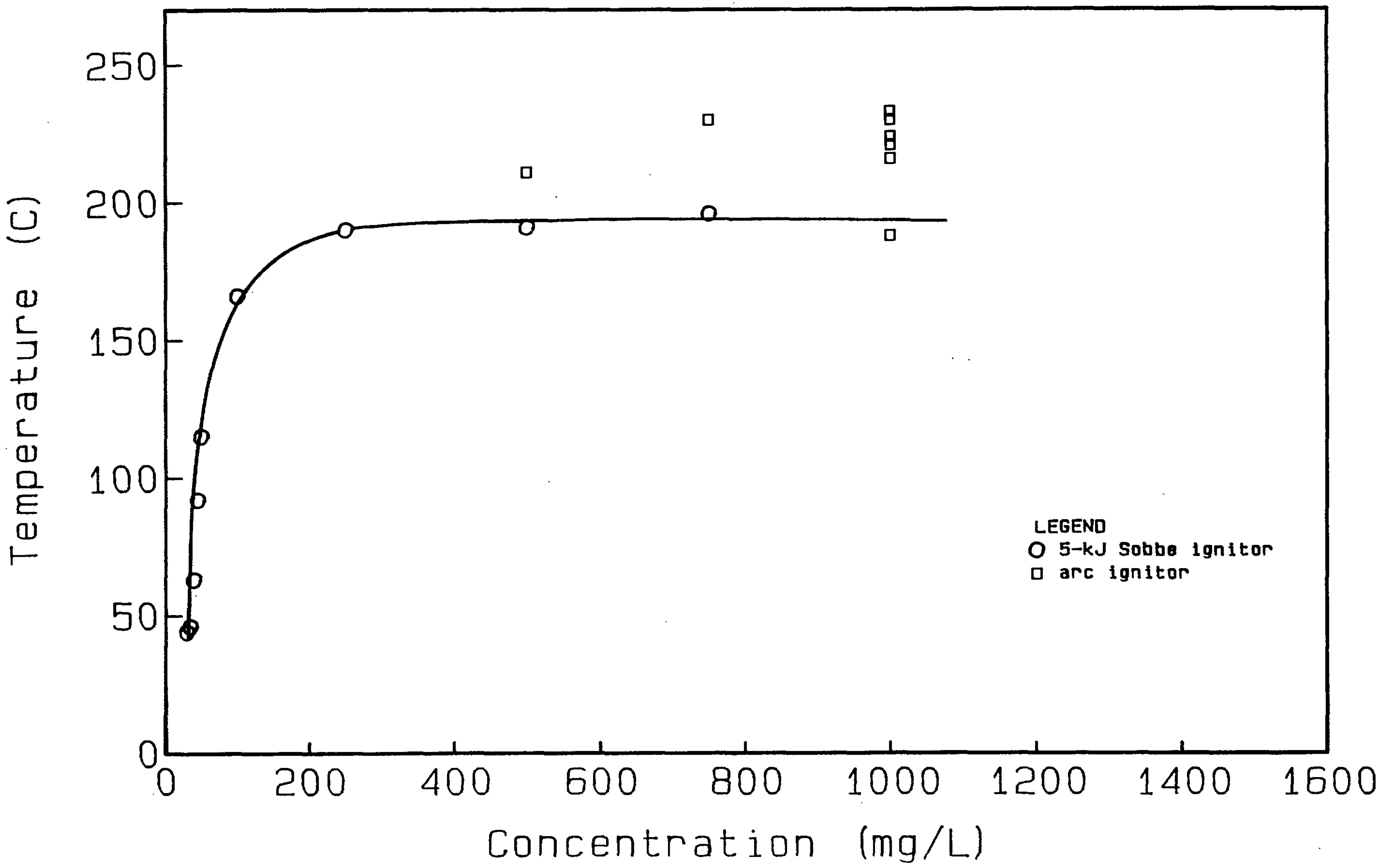


Fig.8.Lingan Mine Coal Dust: Min. Expl. Conc.

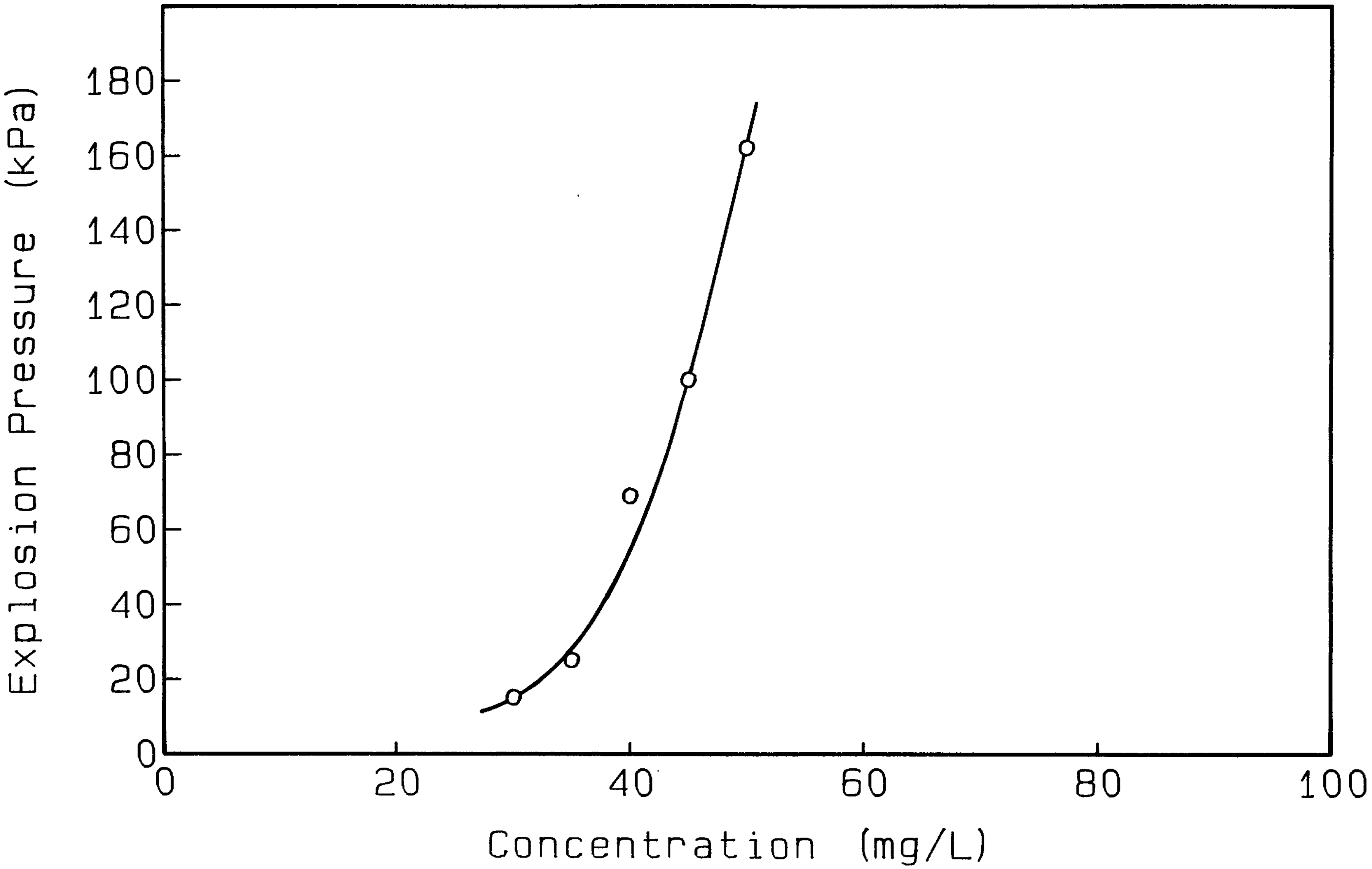


Fig.9. Lingan Mine Coal Dust: Min.Oxygen Conc.

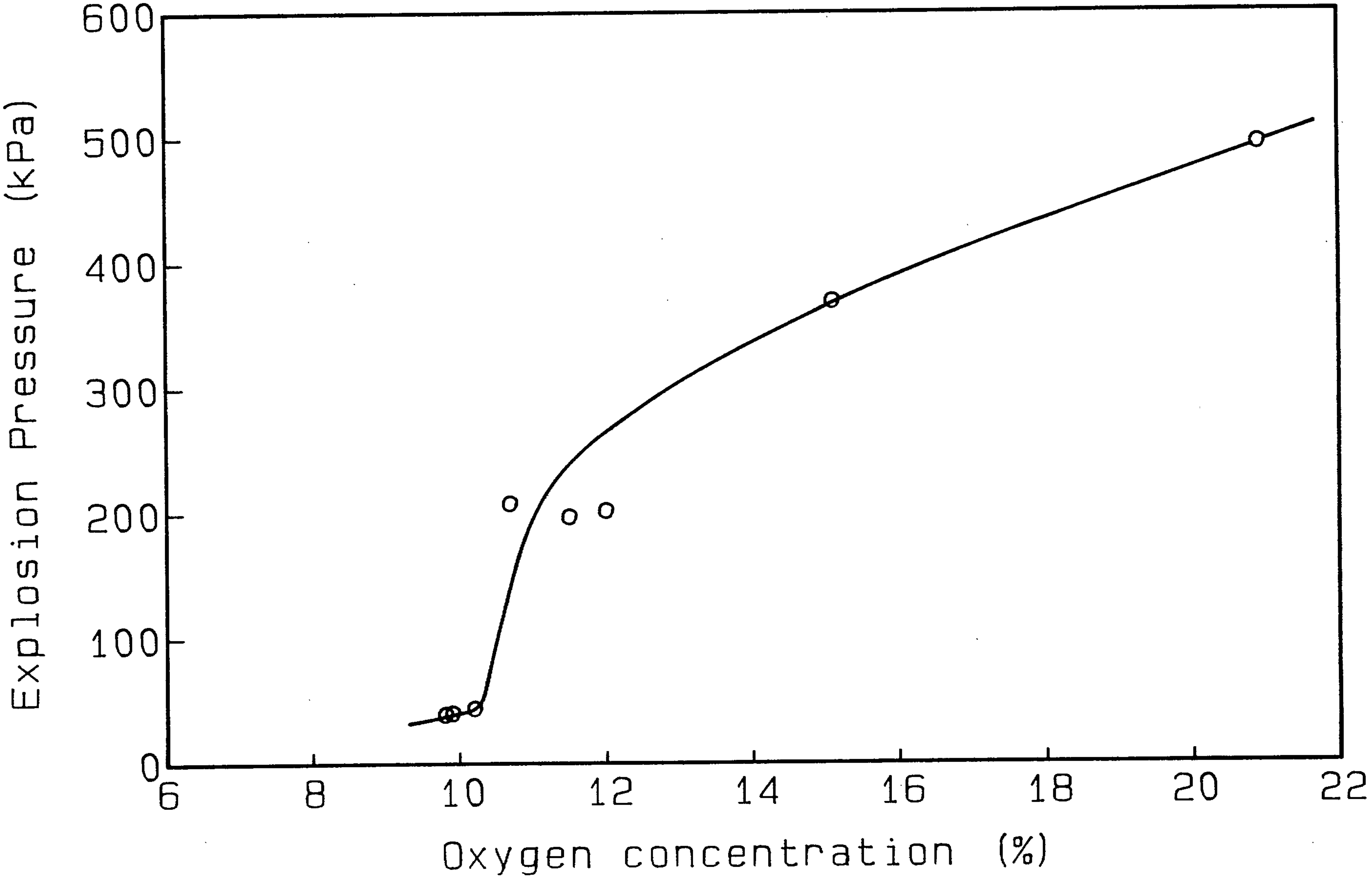


Fig.10.Lingan Mine Coal Dust: Min.Oxygen Conc.

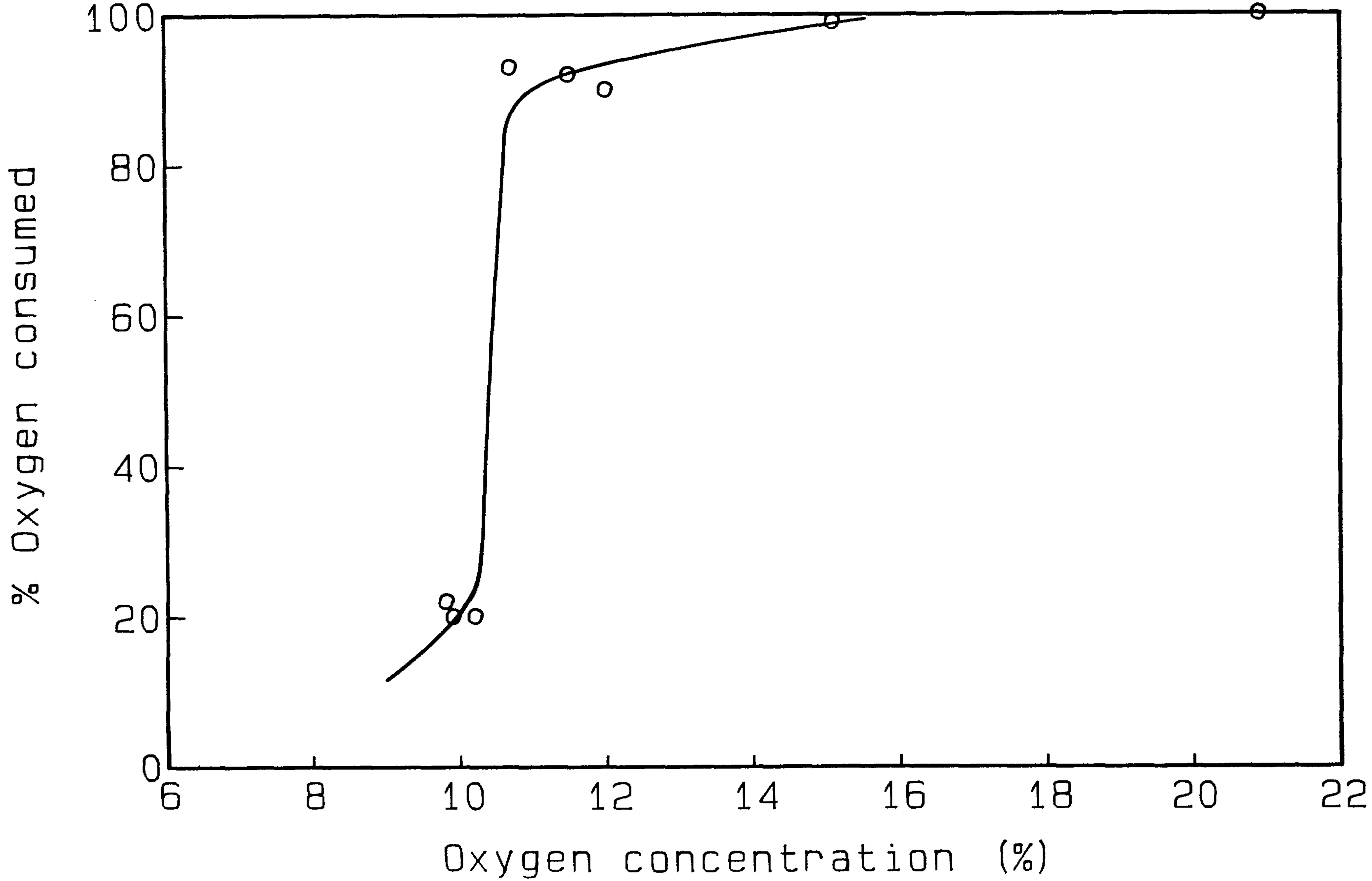


Fig.11.Lingan Mine Coal Dust: Min.Oxygen Conc.

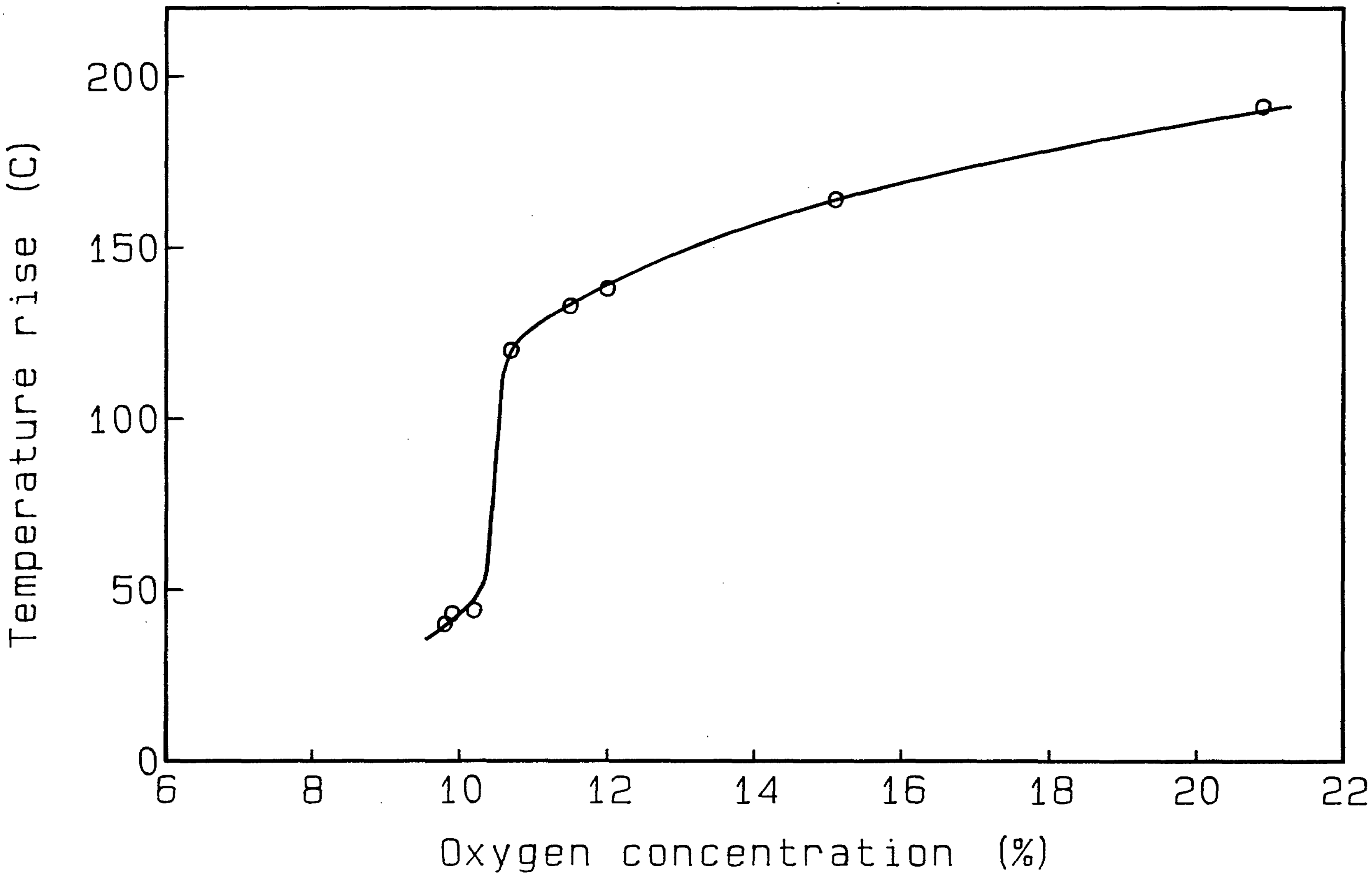


Fig.12.Highvale Mine Coal Dust: Max. Pressure

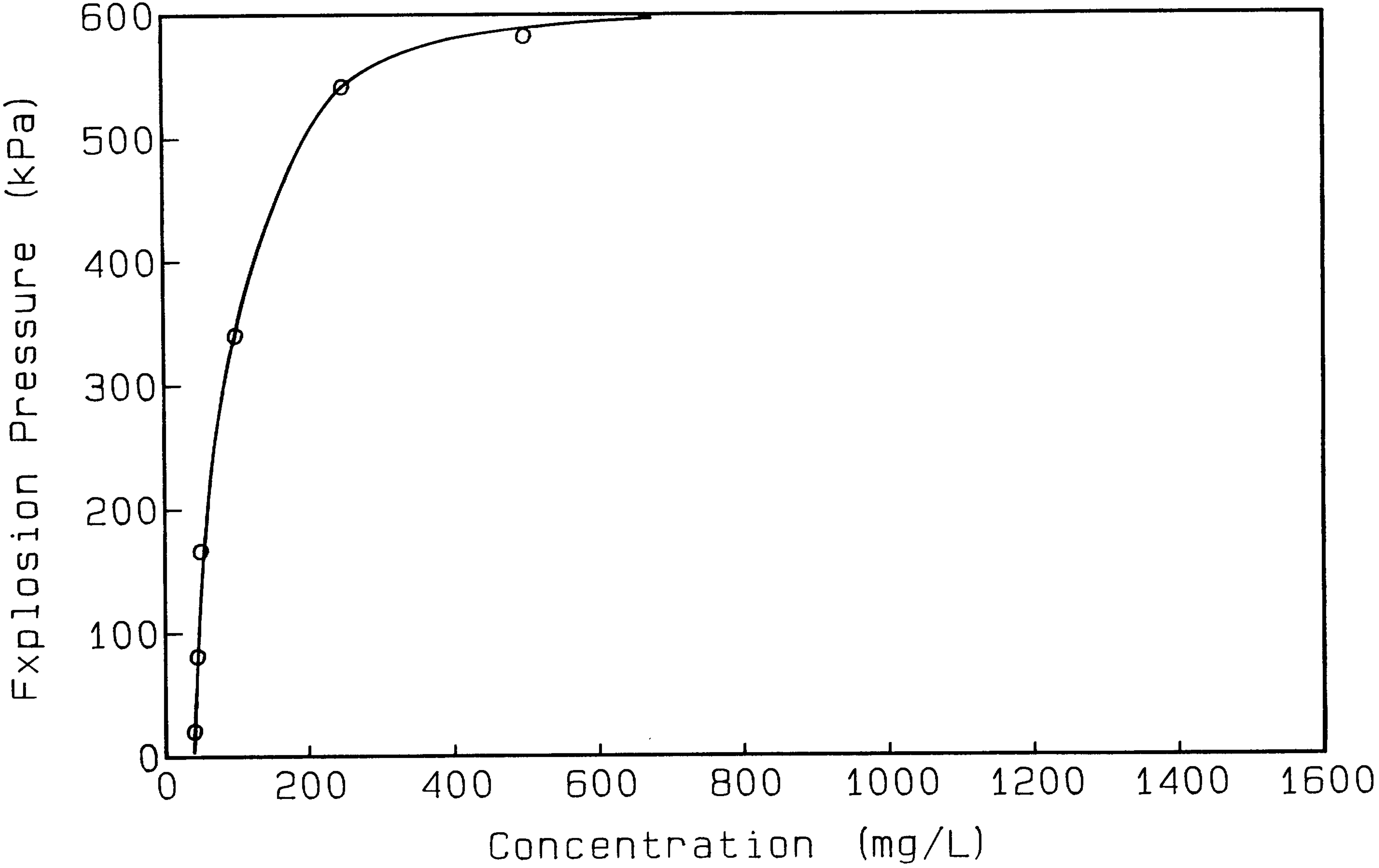


Fig.13. Highvale Mine Coal Dust: Oxygen Consumed

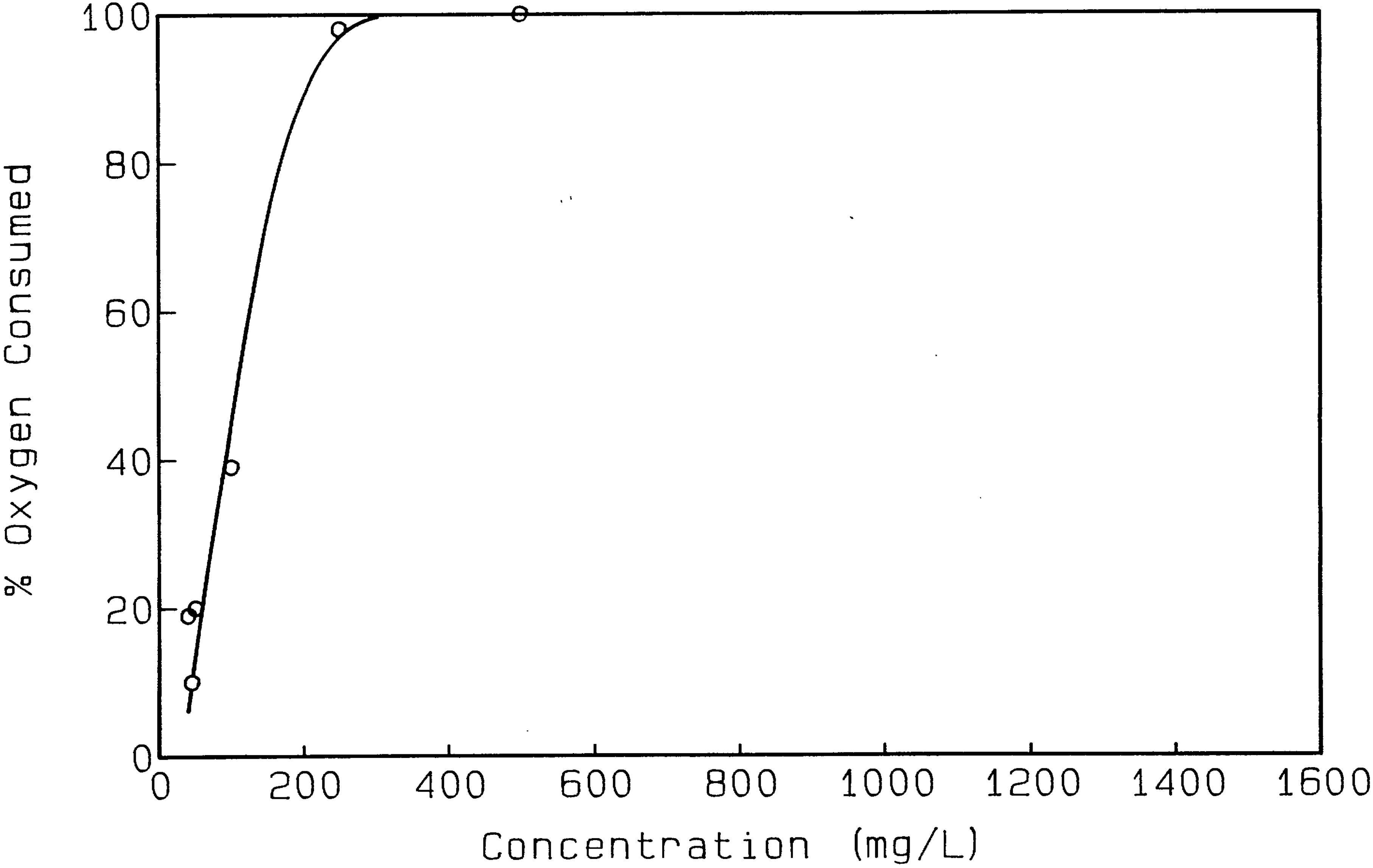


Fig.14.Highvale Mine Coal Dust: Temp. Rise

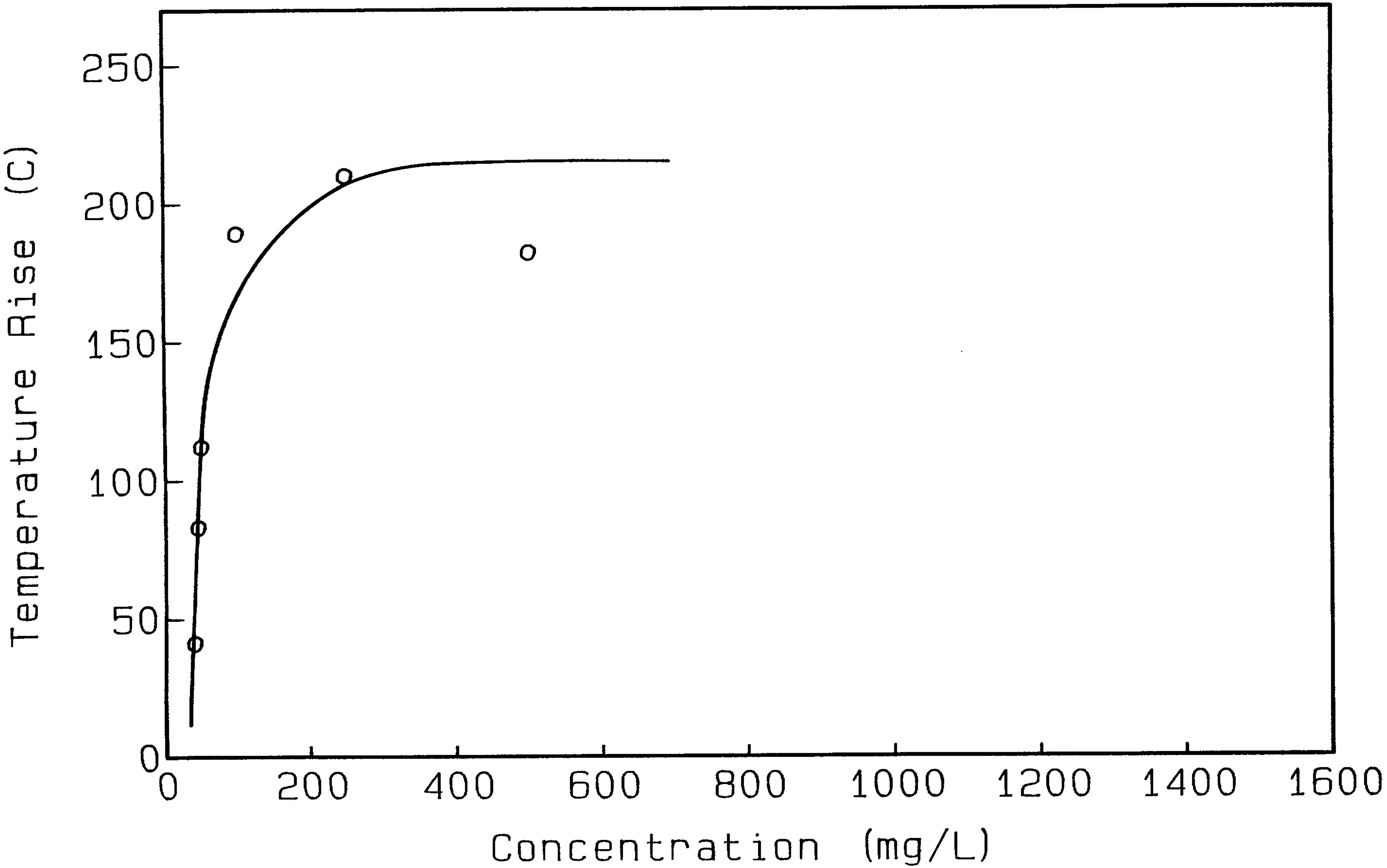


Fig.15.Highvale Mine Coal Dust: Min.Oxygen Conc.

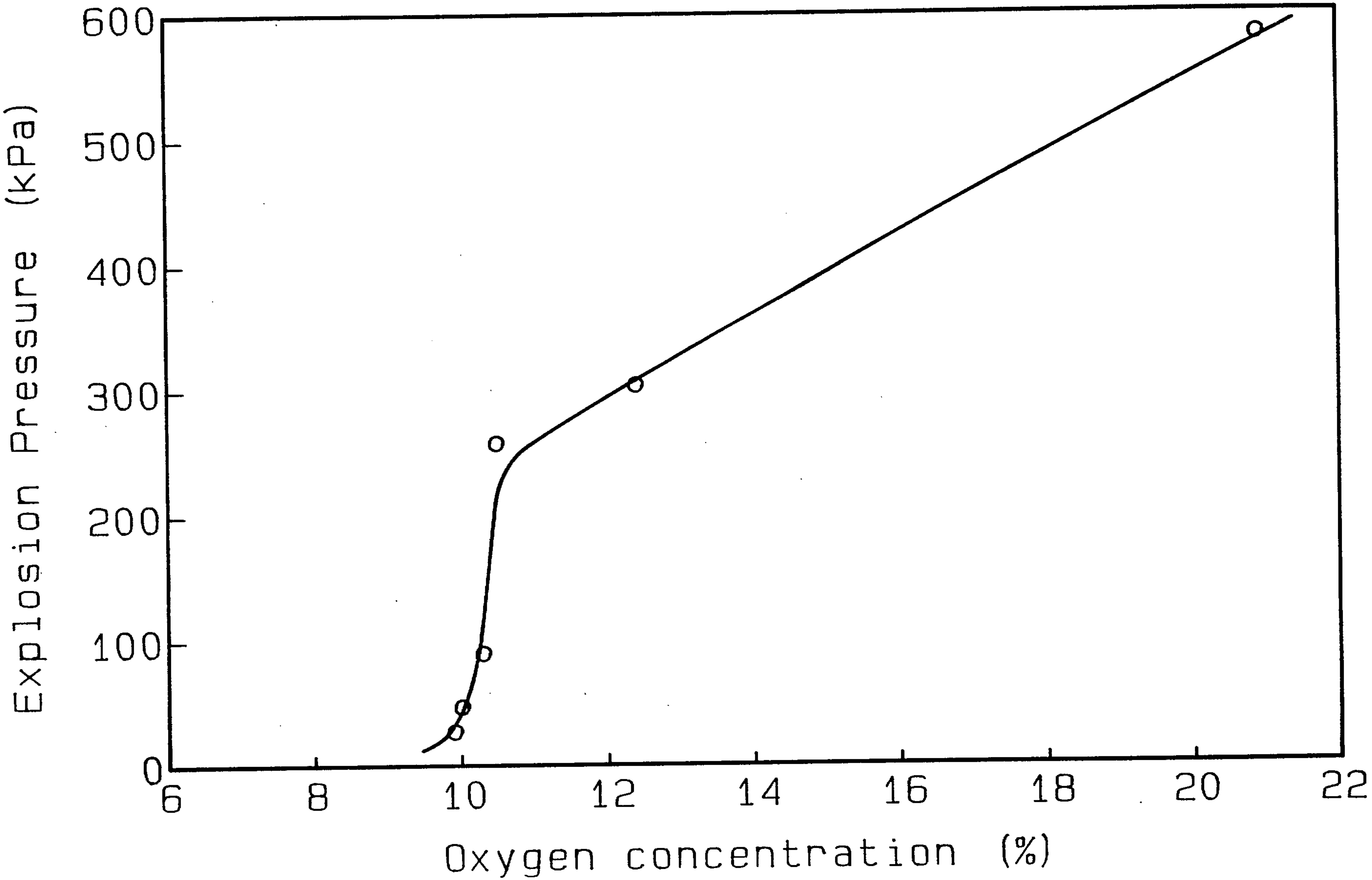


Fig.16.Highvale Mine Coal Dust: Min.Oxygen Conc.

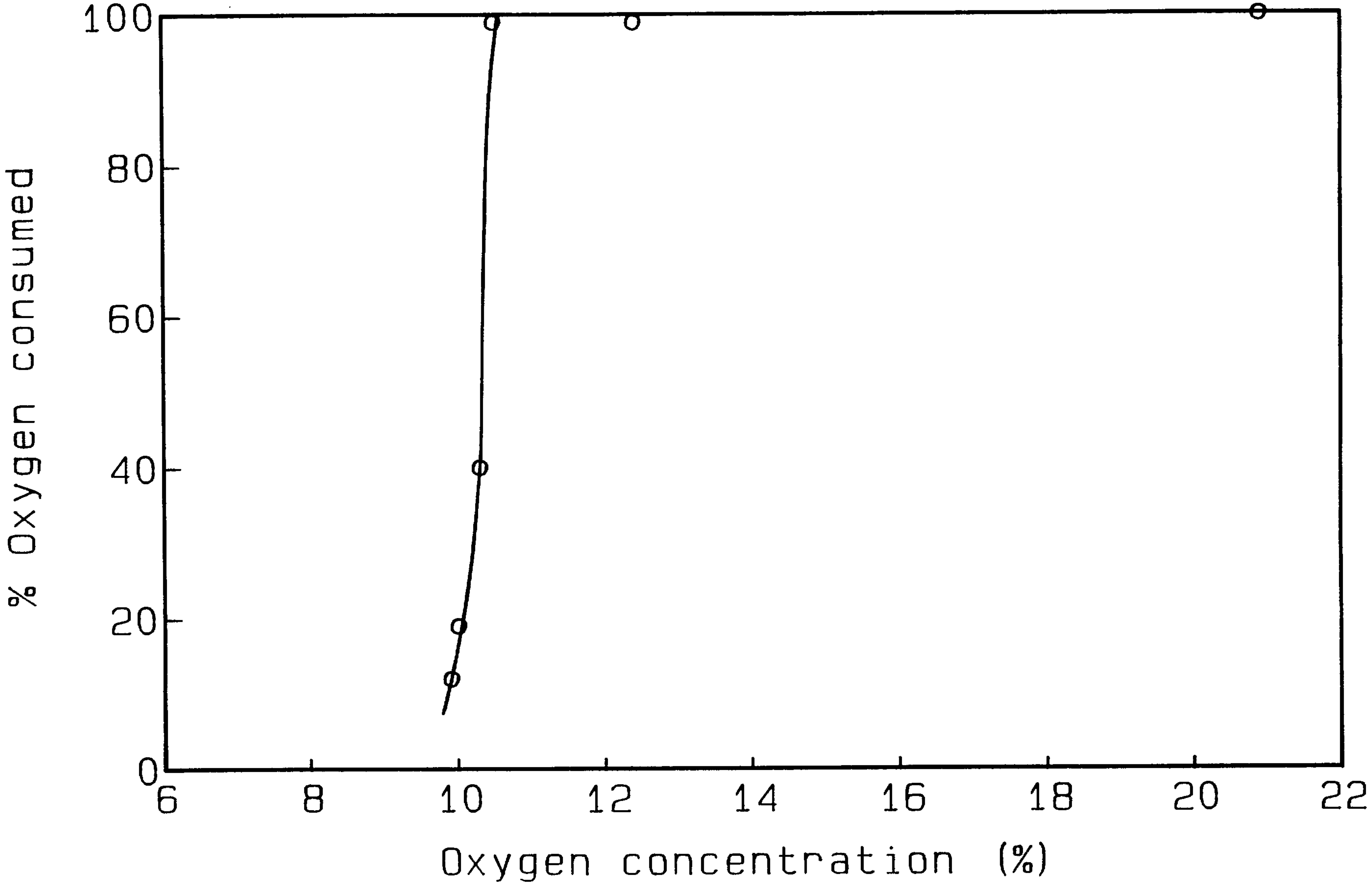


Fig.17.Quintette Mine Coal Dust: Max. Pressure

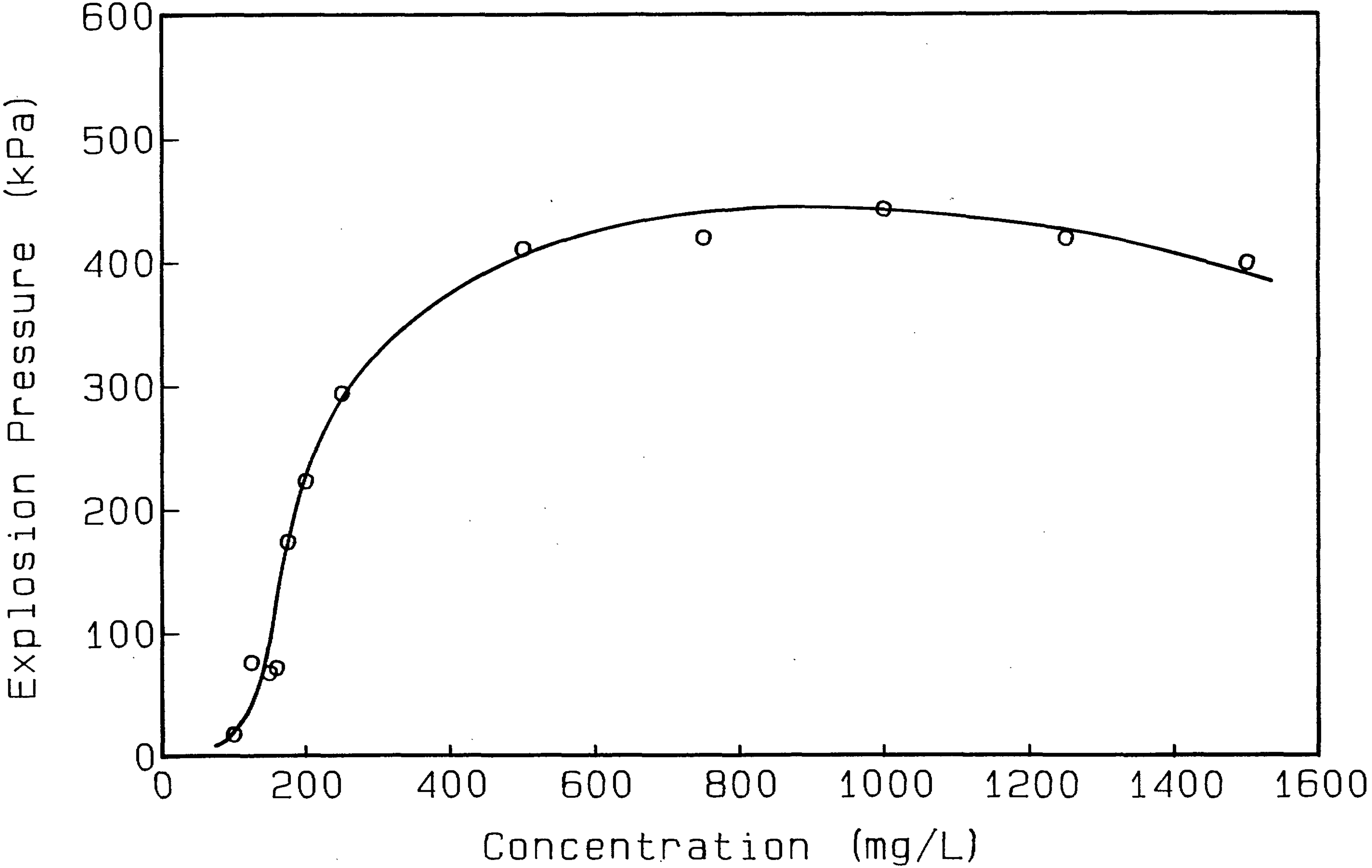


Fig.18.Quintette Mine Coal Dust: (dP/dt) - max.

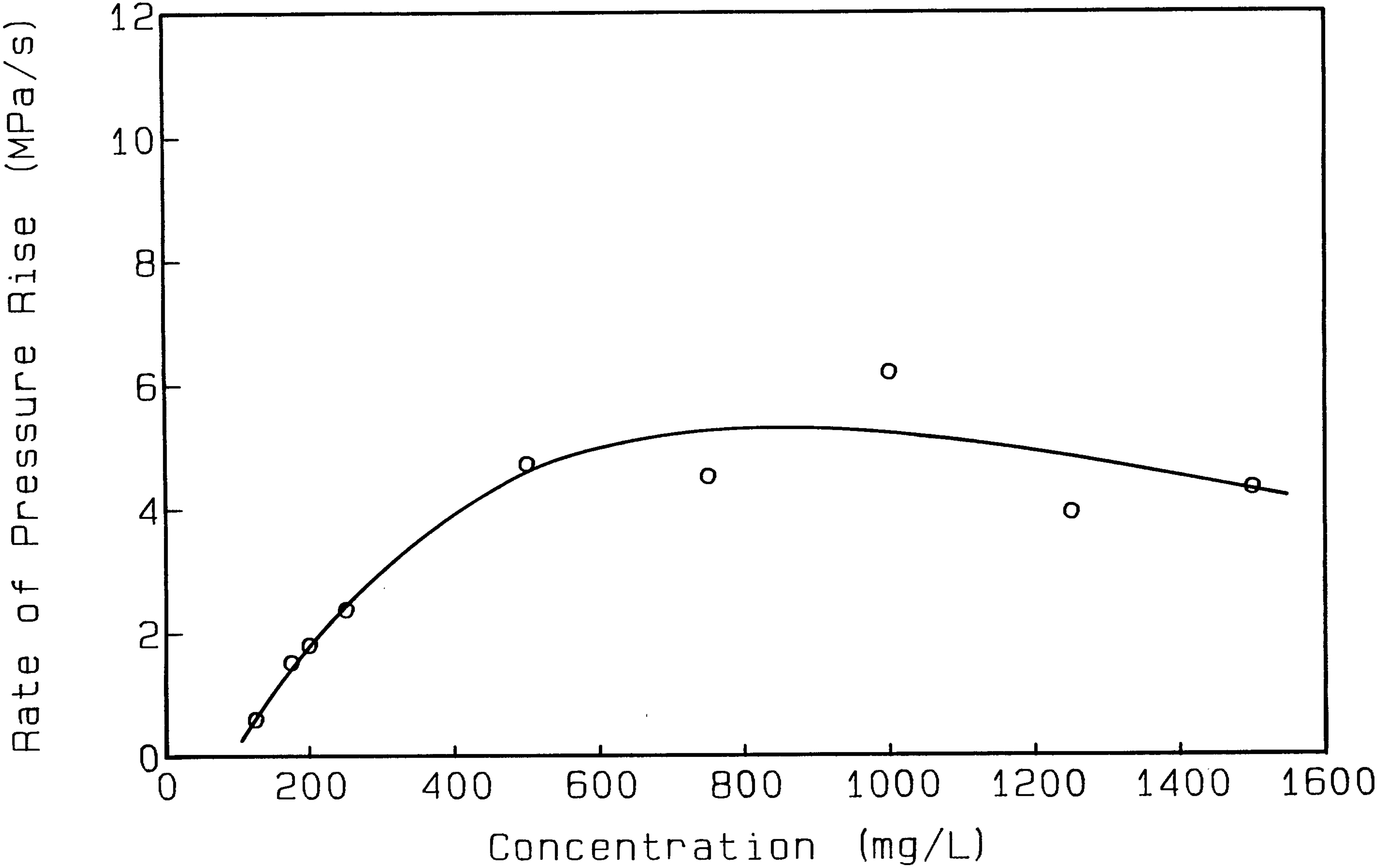


Fig.19.Quintette Coal Dust: Oxygen Consumed

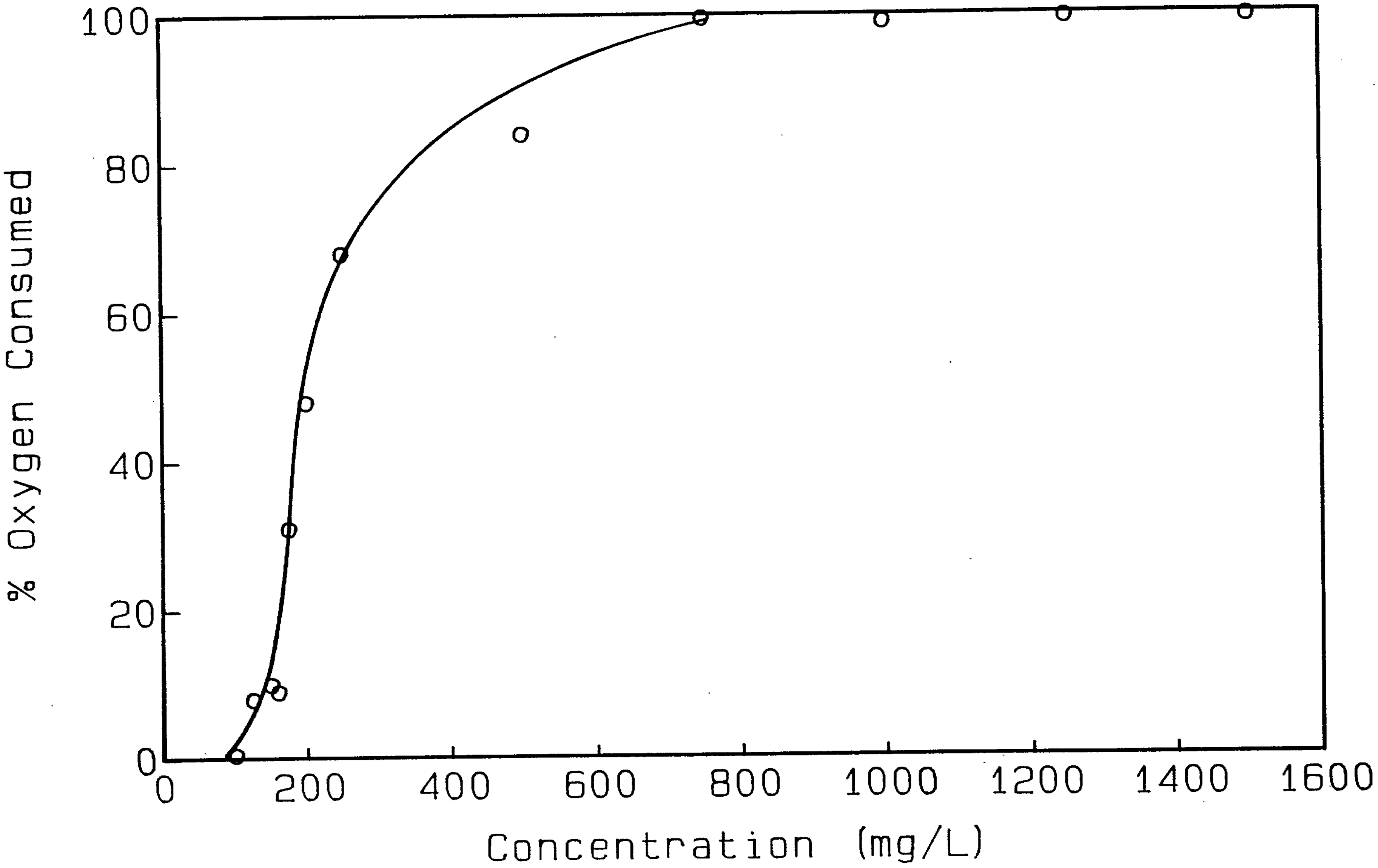


Fig.20.Quintette Coal Dust: Temp. Rise

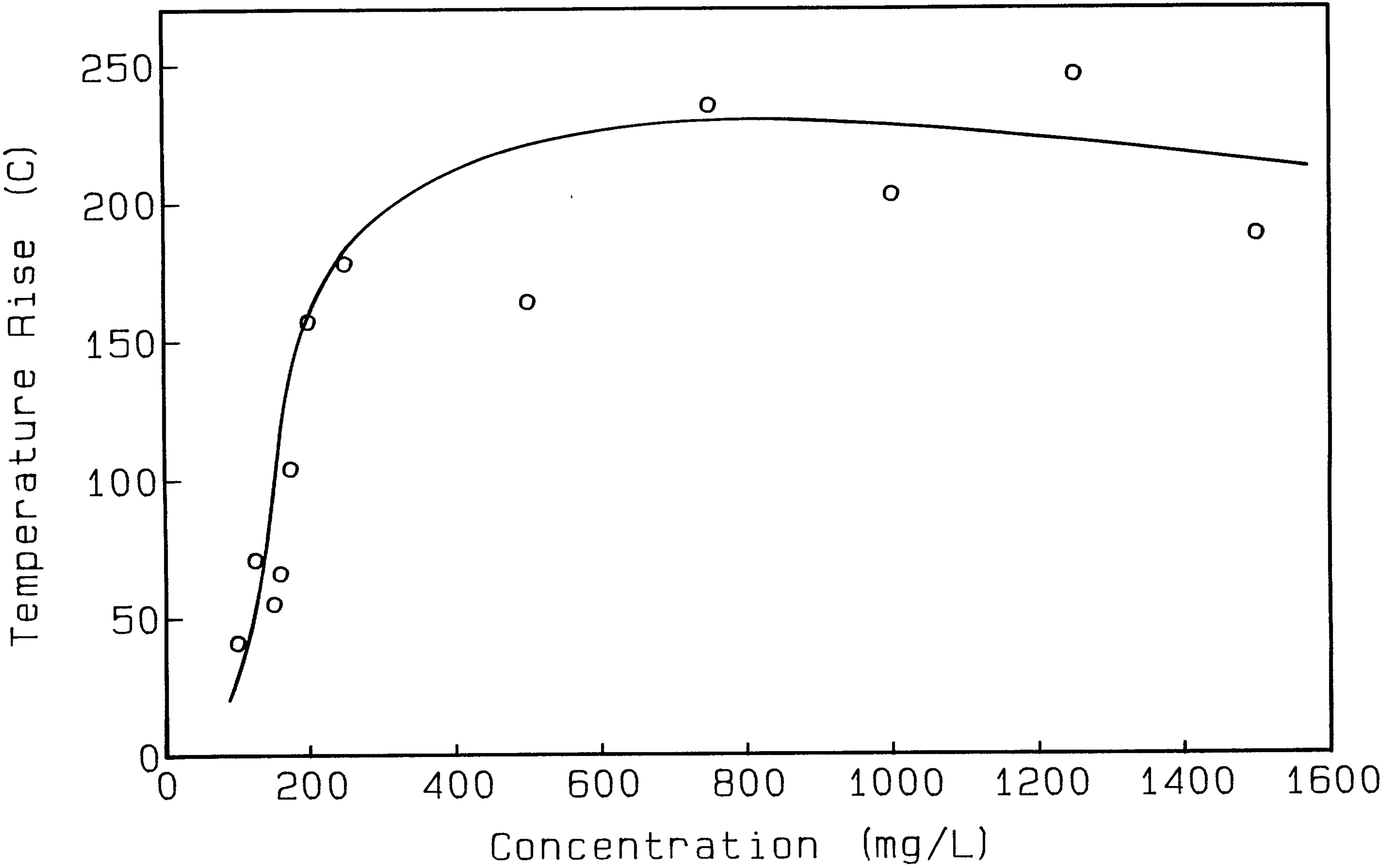


Fig.21.Quintette Coal Dust: Min. Oxygen Conc.

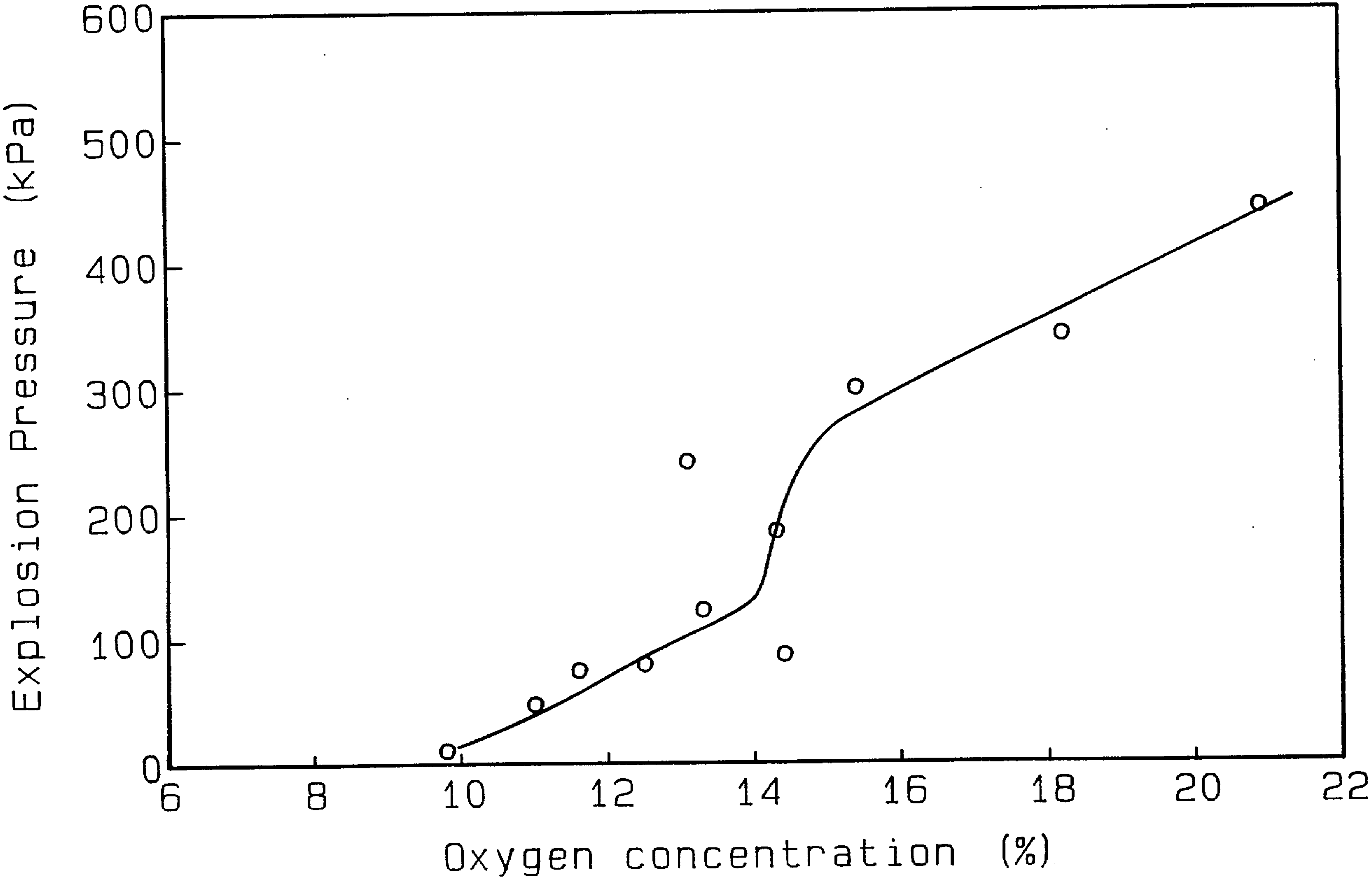
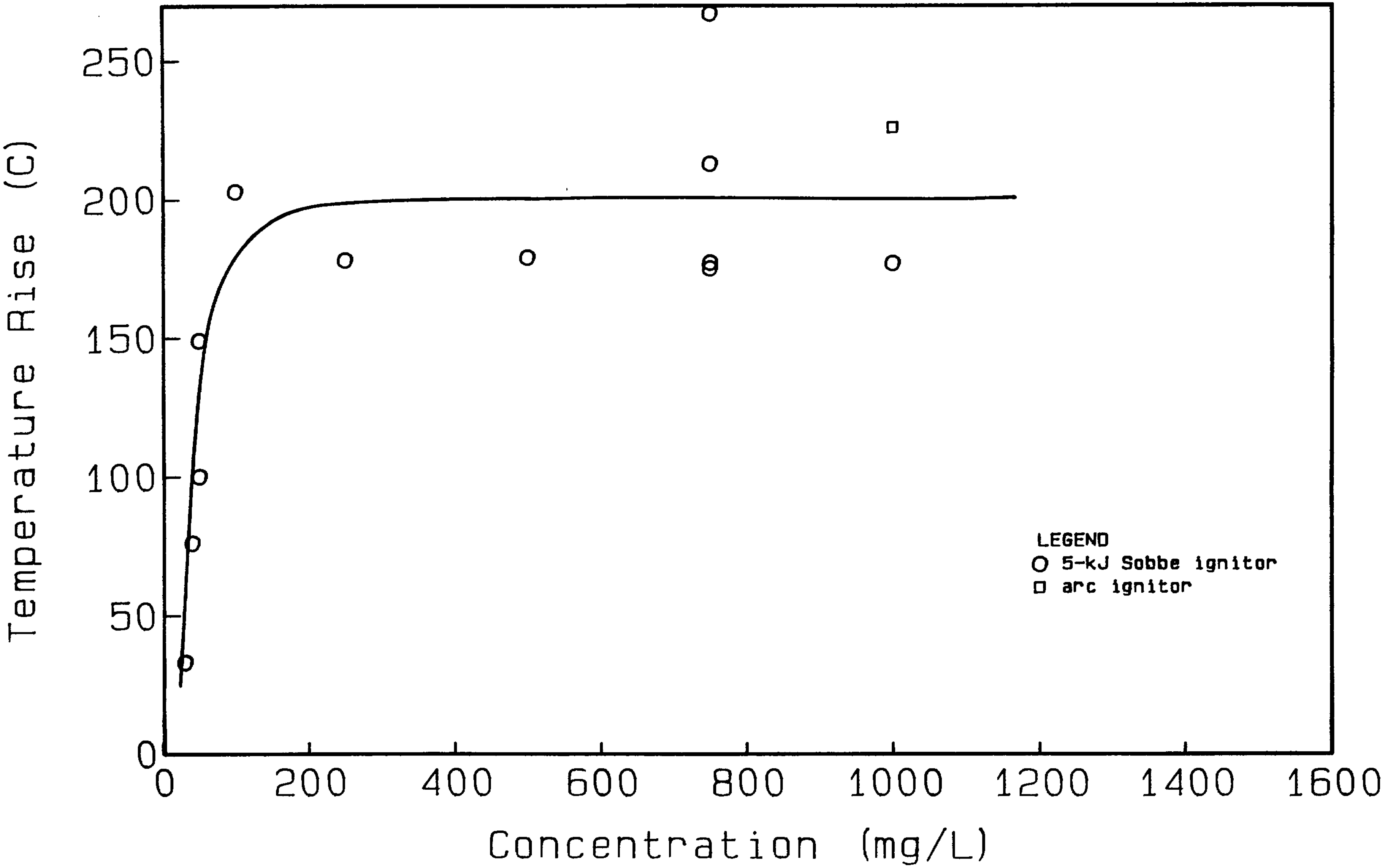


Fig.27.Pittsburgh Std.Coal Dust: Temp. Rise



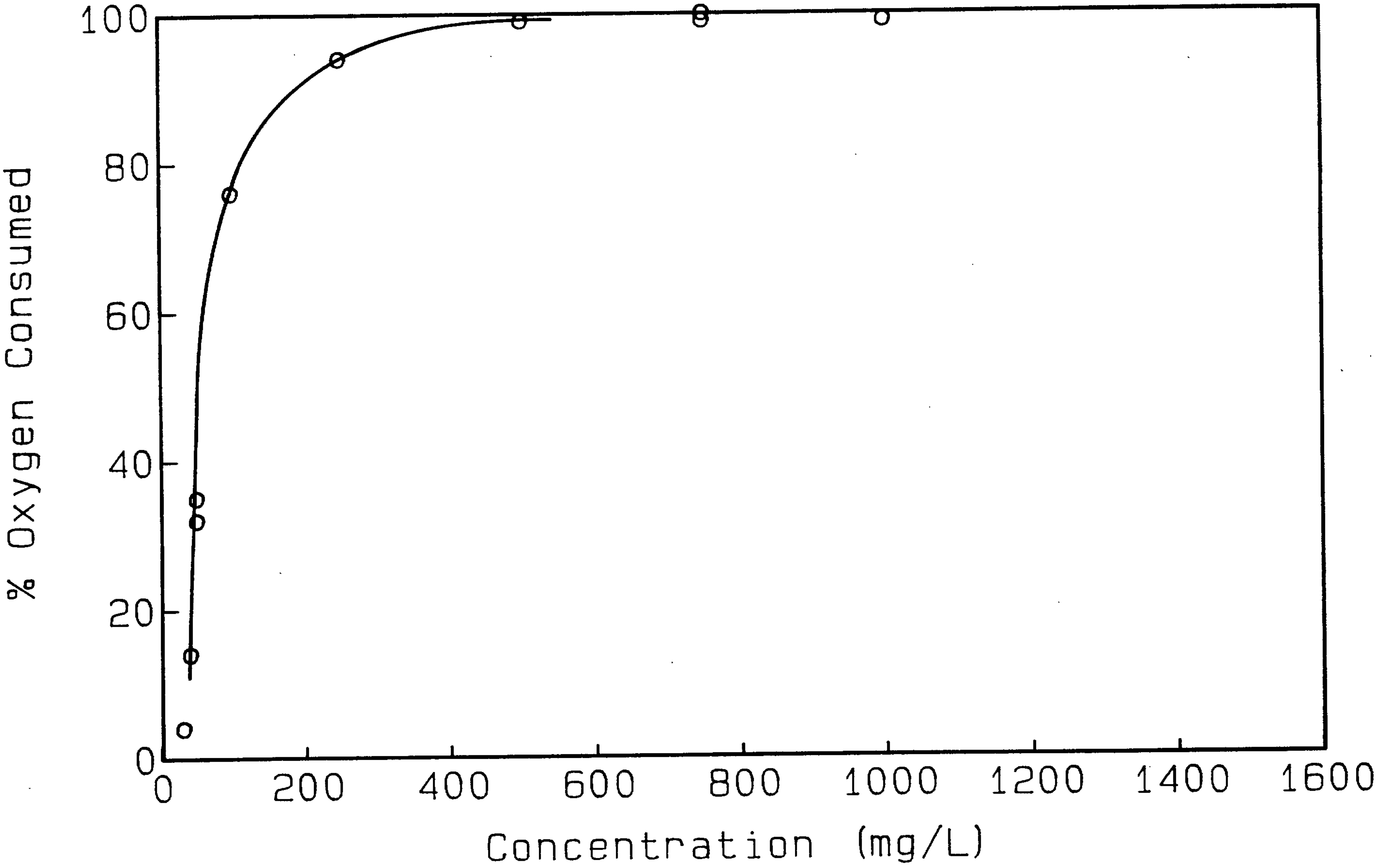


Fig.26.Pittsburgh Std.Coal Dust: Oxygen Consumed

Fig.25.Pittsburgh Std.Coal Dust: (dP/dt) - max.

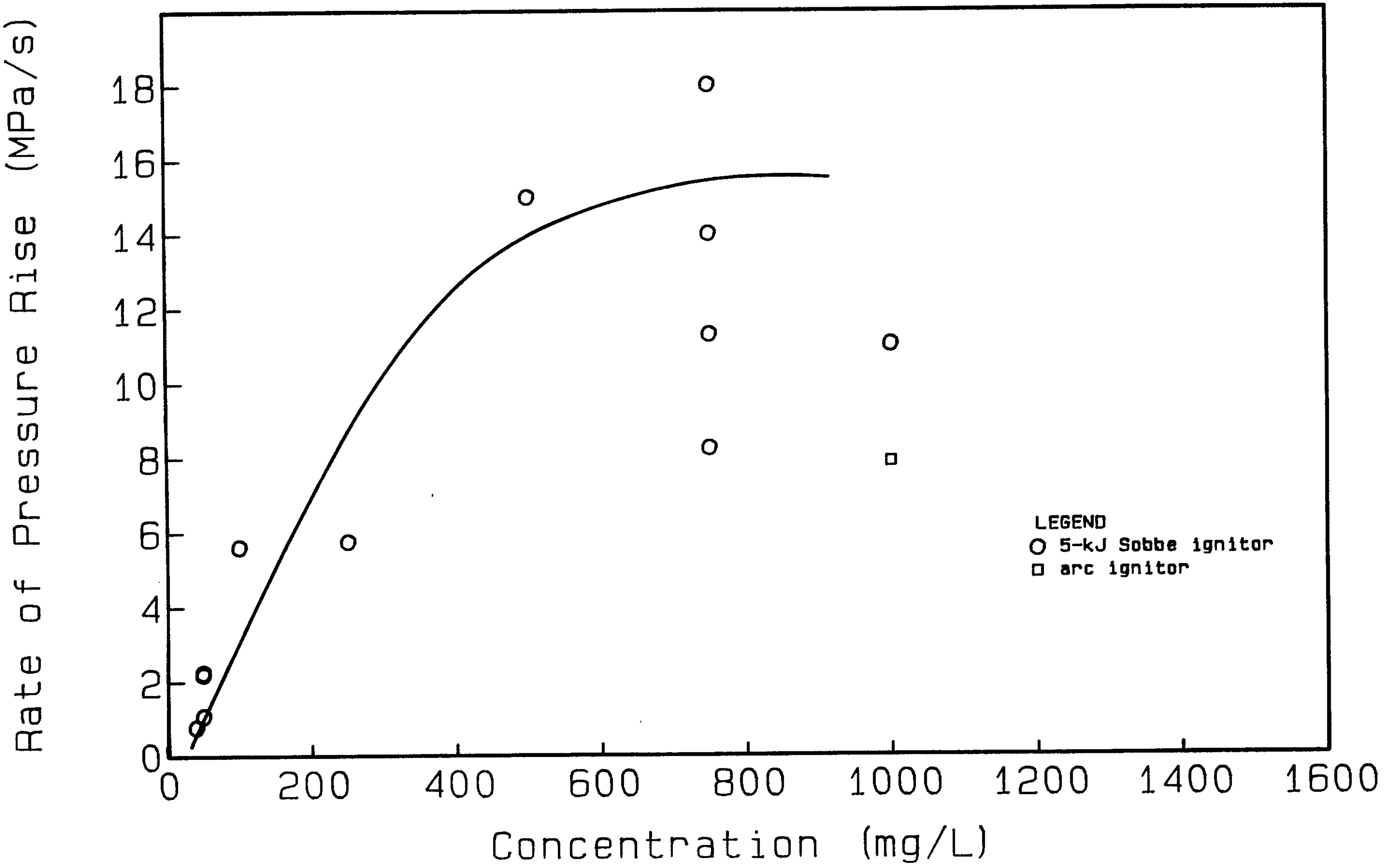


Fig.24.Pittsburgh Std. Coal Dust: Max.Pressure

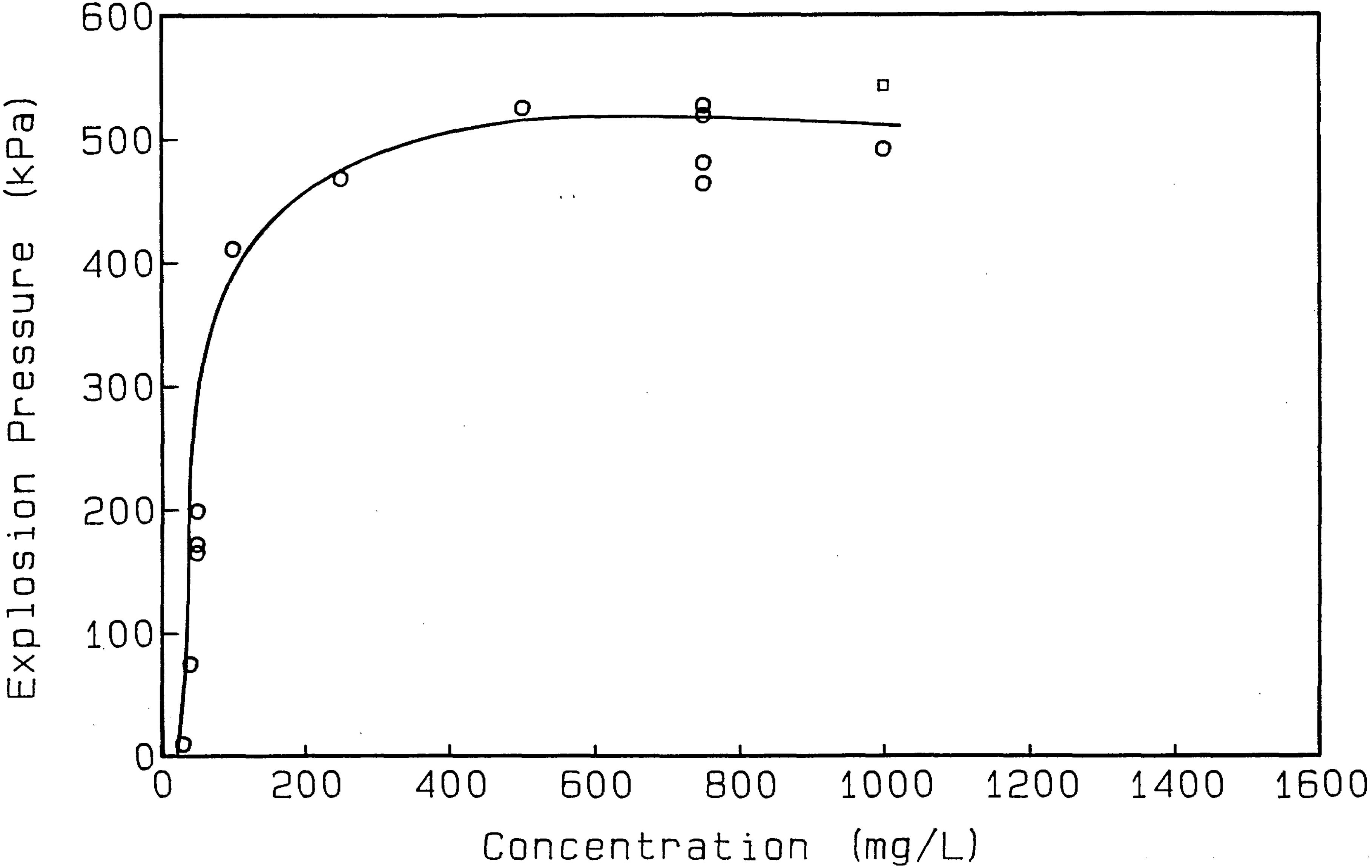


Fig.23.Quintette Coal Dust: Min. Oxygen Conc.

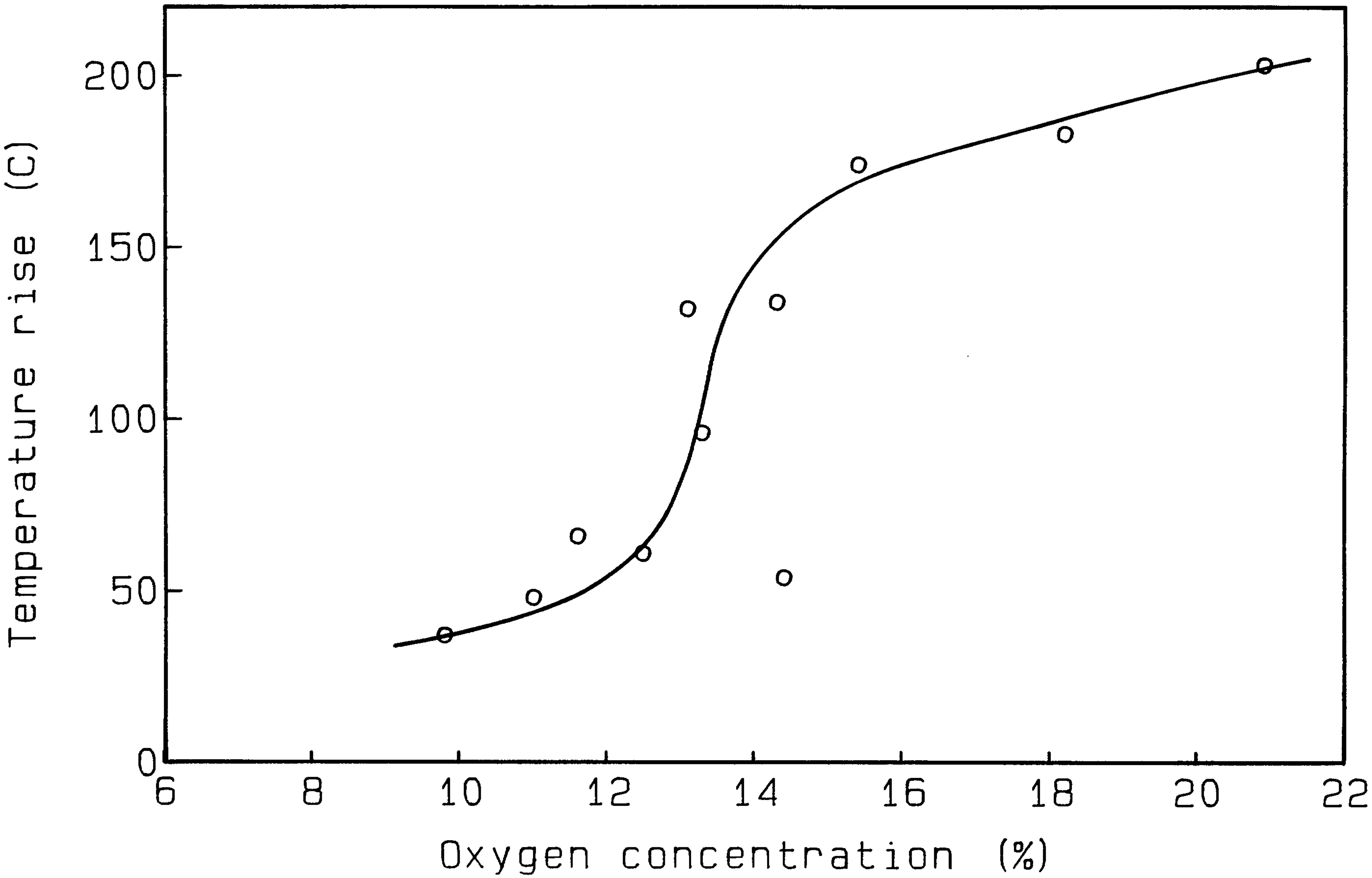


Fig.22.Quintette Coal Dust: Min. Oxygen Conc.

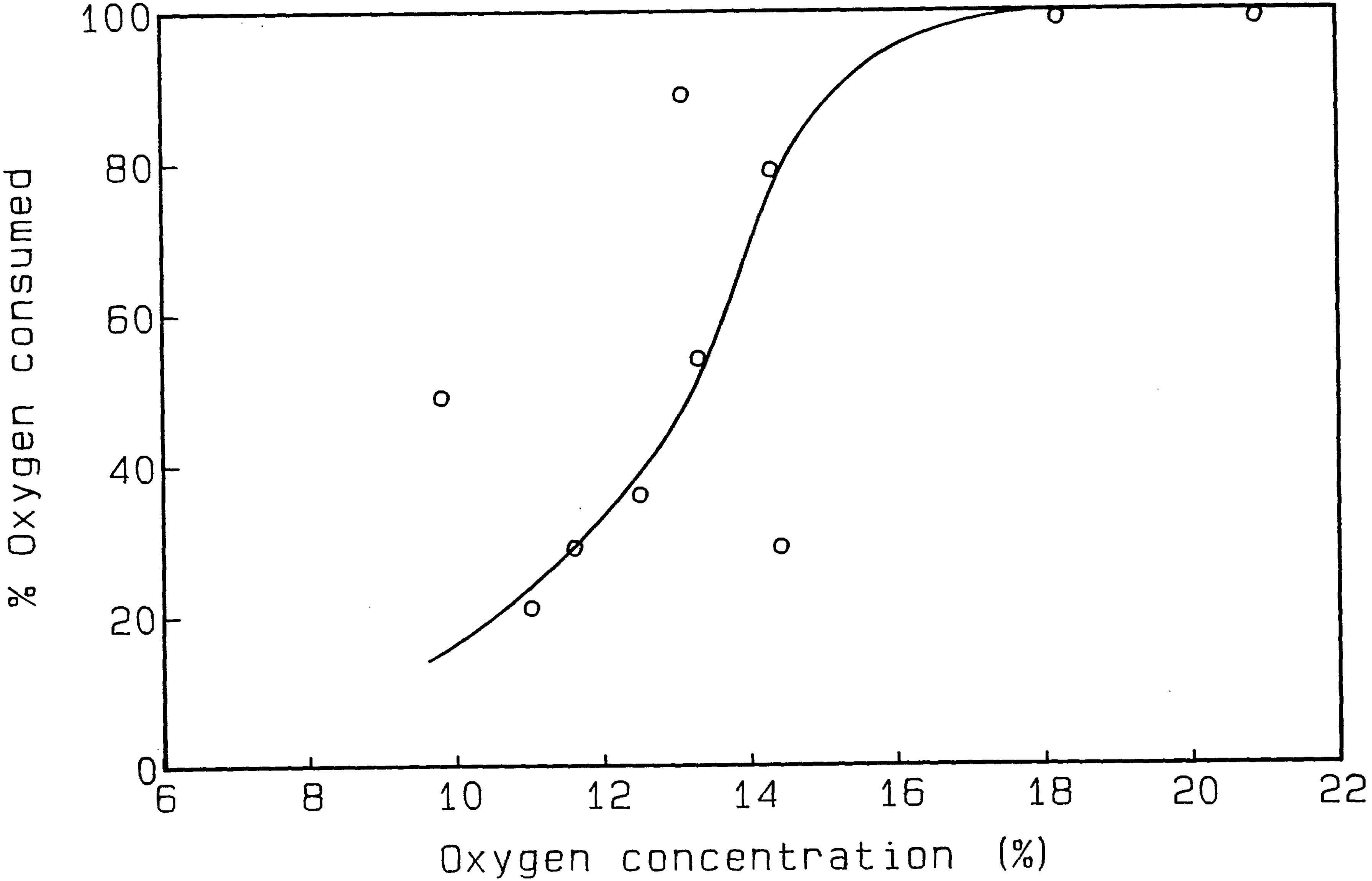


Fig.28.Particle Size Analysis of Coal Dusts