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THE STATUS OF SULPHIDE ORE DUST EXPLOSION CONTROL IN CANADA (1988)

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ABSTRACT: In recent years, as a consequence of an increasing incidence of sulphide ore dust explosions in Canadian mines, a country-wide, multi-participant, collaborative dust explosion control research program was initiated in late 1986. This paper highlights a few of the major issues stemming from the research, discussions and conclusions that have emerged from this collaborative effort involving some thirty participants.

As part of CANMET's contribution, a dust explosion testing facility has been established at MRL near Ottawa. This facility permits the laboratory determination of several explosion-related parameters for ores and pure minerals. A summary of the results of this work is presented.

INTRODUCTION LEARNING FROM THE COAL EXPERIENCE

Explosions in coal mines, attributed at first solely to methane, have been well known and greatly feared for centuries. Around the middle of the nineteenth century, as a result of his investigation into a coal mine disaster, the famous Michael Faraday was among the first to realize that coal dust could play an active and substantial role in explosions in mines. Research into explosion phenomena of both gases and dusts has been ongoing to the present in an effort to avoid major coal mine disasters that unfortunately continue to occur around the world at a frequency of about every six months.

Enright (1) has shown that research studies, and the implementation of resulting improved safety procedures, has steadily reduced the annual death rate in coal mines in spite of substantially increased production and potential for explosions caused by mechanical and electrical equipment. Figure 1, below,

Fig. 1 - Number of persons killed in coal mine explosions 1880 - 1950 (Tideswell 1955)

has been reproduced from Prof. Enright's document to illustrate this point. It should be noted however, that such explosions have not been eliminated, and that there remains a threshold level of incidents which thus far has not yielded to the control measures in place.

SULPHIDE DUST EXPLOSIONS

The conditions necessary for any fire to occur are often described by the "fire triangle": fuel, air and ignition source. If any one of these is eliminated, then a fire can not start. These same three conditions are required for a dust explosion, along with the additional requirement of some degree of confinement, that is, the event must occur in a closed or partly closed space.

For sulphide dust explosions, the fuel is the sulphide ore dust. Pyrite reacts predominantly by the following equations to produce Fe_3O_4 (magnetite) and Fe_2O_3 (hematite):

$$3\ FeS_2 + 8\ O_2 = Fe_3O_4 + 6\ SO_2 + 2370\ \mathrm{kJ/mol}$$
$$4\ FeS_2 + 11\ O_2 = Fe_2O_3 + 8\ SO_2 + 3310\ \mathrm{kJ/mol}$$

In order for the fuel and air to be together, the sulphide dust must be finely divided and suspended in air.

Sulphide dusts are less explosible than most other dusts such as coal or grain; they require a substantial ignition source. In practice, therefore, the ignition source can be attributed to the explosives used for blasting. This is in marked contrast to gas explosions, coal dust explosions and most other dust explosions, where the identification of the ignition source can be very difficult.

The predominant cause of injuries and fatalities due to sulphide dust explosions is not the actual explosion but rather the toxic sulphur dioxide gas produced. A moderate amount of pyrite can generate an astonishing amount of sulphur dioxide, as shown by the following analysis:

Consider a barely-noticeable layer of pyrite dust (0.1 mm thick) on the roof and walls of a 25 m x 25 m x 50 m stope void. If all this dust reacts, about 800 m^3 (at standard temperature and pressure) of SO_2 would be produced, or about 2.6% of the air in that void, which is about 5000 times the TLV. Another way of appreciating this quantity is that it would fill

10,000 km of a 4 m X 4 m heading with the TLV concentration. It is thus hardly surprising that large areas of a mine have been found to be contaminated after a sulphide dust explosion. The above calculation omitted the very large quantity of dust generated by the blast itself, which would be ideally located to ignite.

In the Fox mine, for example, "the explosion caused the 4-5 stope to upcast to the surface through the shaft and through drill holes. Sulphur dioxide polluted the air in the head frame and shifter's offices, where the crews had taken refuge from the stope blast and forced the crews outside to the machine shop. The slow wind present that evening drifted the sulphur dioxide-laden air into the machine shop and concentration plant and these places in turn had to be evacuated." (1) At the GECO mine, the one fatality and the injuries were sustained 2256 m from the stope explosion as a result of SO_2 exposure (2).

CURRENT CONTROL METHODS

Because sulphide dust explosions occur only immediately after a blast, many mines prevent the possibility of injury by removing personnel until the area has been tested for SO_2 after the blast. However, this procedure does not help productivity.

To prevent the actual sulphide dust explosions, a number of mines have experimented with changing the delay patterns in blasting and using limestone dust or water as inhibitors. Although some successes have been reported, there remain numerous questions as to their effectiveness.

It is suggested in (1) that at least part of the reason for continuing incidents may be that fundamental information, while known, is not well disseminated. For example, laboratory data suggests that stone dust (calcium carbonate) must form approximately 75% of the airborne sulphide dust mixture to render it non-explosible. Therefore, the practice of pre-detonating and dispersing a few bags of dust before a stope blast, is unlikely to contribute significantly to the prevention of explosions.

THE COLLABORATIVE PROGRAM

The fatality at Geco Mine in 1985 sparked an awareness of the seriousness of the sulphide dust explosion problem in Canadian mines and led to the first conference ever held on this subject, in Manitouwadge, Oct. 1986 (3). A "Dust Explosion Control Group" was formed there, consisting of representatives of 15 mines, 1 inspectorate, 2 explosives companies, 5 universities, 2 mining associations, 2 governments and 3 other interested parties. Its mandate is to coordinate research in this field.

In 1987, the Dust Explosion Control Group formed a Task Force of 5 mining companies suffering the greatest number of incidents, and assisted administratively by CANMET. The purpose of the Task Force is to systematically investigate, in a carefully controlled fashion, the efficacy of present inhibition practices by in-mine studies in order to improve effective procedures and eliminate the ineffective ones. It is anticipated that this work will begin in 1988.

A session on sulphide dust explosions was organized for the 90th Annual General Meeting of the CIM in Edmonton in May 1988. Eight papers were presented, which will be published shortly by the CIM.

"NON-INCENDIVE" EXPLOSIVES

Since the sole ignition source for sulphide dusts is the explosives, development of an explosive that would not ignite the dust would seem to be a route well worth-while exploring. For coal mines, regulations specify that "permitted" explosives be used that do not ignite methane/air mixtures when used in the prescribed manner (small blasts). Permitted explosives are, in general, weaker than conventional explosives and therefore would not be able to break the type of rock that occurs in metal mines. Moreover, modern mining techniques use large-scale blasts, well outside the acceptable range of the permitted explosives.

Explosive Technology International jointly with the U.S. Bureau of Mines are developing new explosives for oil-shale mines, whose dust has similar explosibility as the sulphide ores (4,5). The early test-work is promising. Field trials at Brunswick Mine are anticipated in the not-too-distant future.

According to the theory of the ignition of the sulphide dust by the hot gases produced by the explosive, anything that would cool these gases before they exit the bore holes should be beneficial. Therefore, more and better stemming may decrease the probability of explosions.

Unfortunately, the two methods mentioned in the preceding paragraphs may not be practical for all situations, either for physical or economic reasons.

CANMET CONTRACTS

As part of its contribution to solving the sulphide dust explosion problem, CANMET has awarded several contracts, which are described below.

Prof. Enright has prepared a state-of-the art review of sulphide dust explosions (1).

Noranda Research, Pointe-Claire, Quebec is carrying out a study to quantify the SO_2 and dust produced during blasting. This information is required so as to be able to calculate the amount of inert dust necessary to prevent a sulphide dust explosion and the possible effects on the mine ventilation system if a dust explosion is not prevented. Equipment is to be developed to be able to make measurements in a mine. A report on this study should be available from CANMET in mid-1989.

Whiteshell Nuclear Research Establishment, Pinwawa, Manitoba, has started a study of the scale-effect of dust explosions, using their existing 10 m^3 cylindrical and 6 m^3 spherical vessels. They will carry out explosion tests on sulphide dusts, as well as other explosible dusts, to determine the validity of small-scale laboratory explosion tests. A report on this work will be available in mid-1990.

Professors Lee and Knystautas of McGill University have carried out several studies over the past few years on the fundamental aspects of dust explosions. Although sulphide dusts were not used (coal was the main emphasis), some of the information obtained and conclusions derived are applicable to all types of dust explosions. These reports are available from CANMET (6).

CANMET'S DUST EXPLOSION LABORATORY

The laboratory has recently completed constructing a laboratory and equipment so as to be able to carry out all standard tests for dust explosibility using up-to-date equipment. The classical Hartmann apparatus is used for measuring the maximum explosion pressure and the maximum rate of pressure rise. Air in ahigh pressure reservoir is released quickly through a solenoid and enters the steel tube in which dust has been placed. An electrical discharge ignites the resultant dust/air mixture and a pressure transducer detects the pressure rise. An improved system for controlling the sequence of events and obtaining a pressure trace was developed in our laboratory. A somewhat different apparatus is used to determine the minimum explosible concentration, which is the smallest amount of dust in air that can form an explosive mixture.

A newer explosion test apparatus, the "20-L vessel" has been commissioned. It also is used to obtain the maximum explosion pressure and the maximum rate of pressure rise. It can also be used to determine the minimum explosible concentration test. We have connected up an infrared spectrometer to enable the measurement of SO_2 after the explosion test and an oxygen analyzer to enable the measurement of oxygen before and after the test.

The minimum spark energy required for ignition of a dust cloud is sometimes of interest. An apparatus has been built by MRL to generate sparks of known energy to enable such tests to be carried out.

The minimum ignition temperature of dust clouds is determined by passing a cloud of the dust downwards through a vertical tubular furnace. The lowest temperature at which one can observe ignition from the open end of the furnace is the minimum ignition temperature.

Grinding, sizing and drying equipment are also installed in the dust explosion laboratory to prepare samples for laboratory tests.

With our optical image analyzer, the sizes and shapes of particles before and after the explosion tests can be measured.

The services of the dust explosion laboratory are available on a cost-recovery or shared-cost basis to all Canadian industries.

LABORATORY TESTS ON SULPHIDE ORE DUSTS

Twenty-eight sulphide ore dust samples of varying composition from 11 11 mines were tested for explosibility (7). For convenience, the explosion pressures were expressed relative to pure pyrite, set to 100. Fig. 2 shows all the results as afunction of sulphur content. There appears to be a sharp cut-off at about 26% sulphur. The large scatter indicates that the explosibility is not simply a matter of sulphur content.

The explosion pressure of 7 pure sulphide mineral samples was determined, as shown in Fig. 3, again as a function of sulphur content. Clearly, different minerals have different intrinsic explosibilities apart from their sulphur contents. This may, at least partly, be understood on the basis of the quantity of energy released when they react with oxygen to form the oxide: pyrite produces more energy than pyrrhotite, which in turn produces more energy than chalcopyrite. This is in the same order as the explosion pressures. Galena does not fit this series because it reacts to form the sulphate rather than the oxide. Although galena is potentially capable of causing blast damage, the fact that it produces only the sulphate means that no toxic SO_2 gas is produced. Sphalerite would not explode under the experimental conditions employed possibly because the reaction to the oxide is much less energetic than the others.

An interesting aspect of the explosibility of the iron ores is the formation of magnetite when the explosion is stronger and hematite when the explosion is weaker (in laboratory tests). The latter can be easily observed by its red colour; the former can be detected using a small magnet. It is thought that the same correlation holds true for in-mine explosions, but this has not yet been proved.

A study of the explosibility of dusts from three concentrate operations that handle chalcopyrite ores has also been carried out recently (8).

CONCLUSIONS

As long ago as 1924, SO_2 was known to have killed miners following blasting operations in sulphide ores. CANMET's predecessor carried out research in this area in the early 1960's. Unfortunately, the problem was not eliminated. It is hoped that, with the full cooperation between mining companies, auxiliary industries, academic researchers and government organizations, as exhibited in he collaborative program, a sufficiently thorough attack on the problem will eliminate it within a few years.

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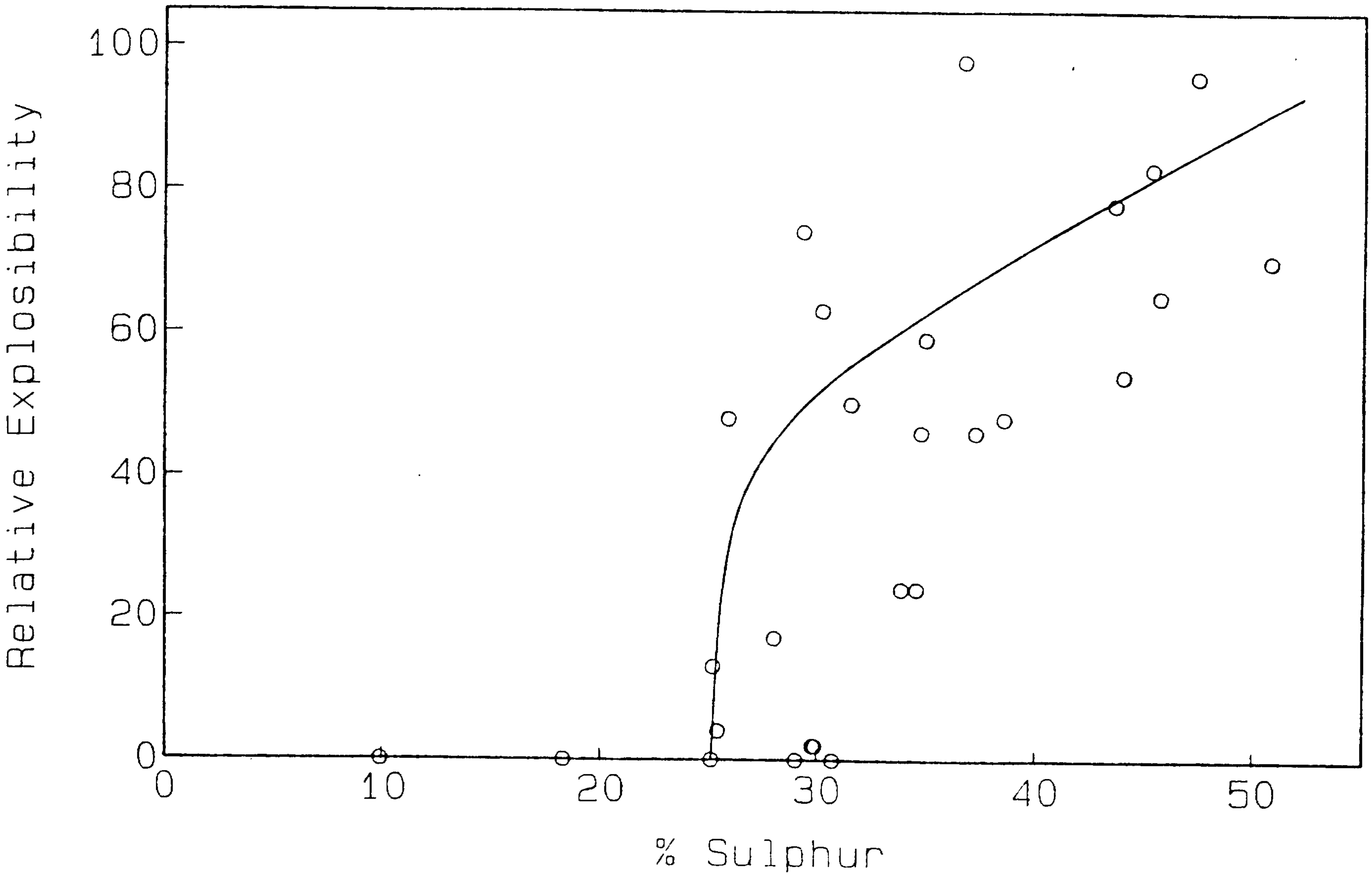

Fig 2. Relative explosibility as a function of sulphur content for ores

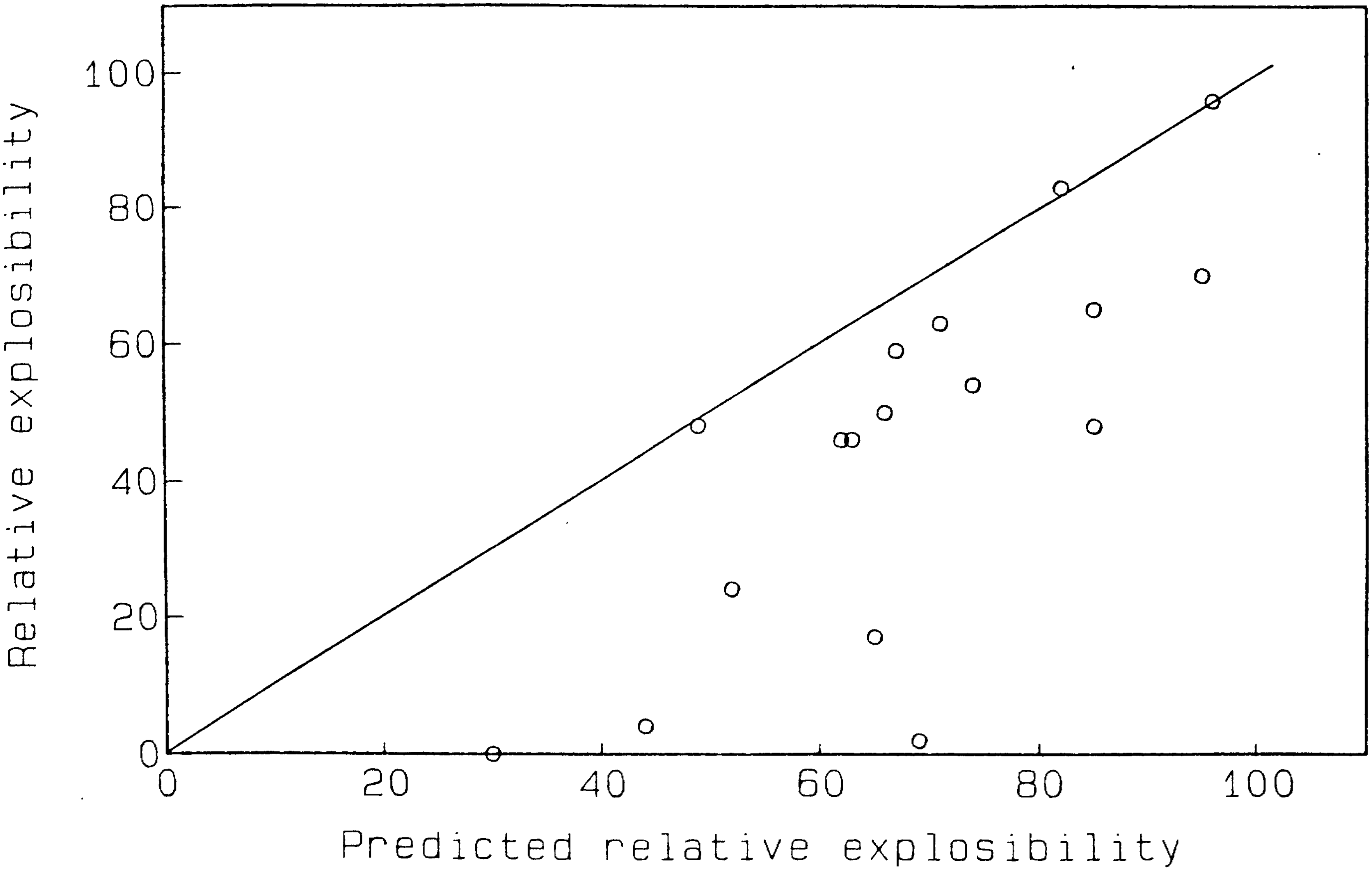

Fig 3. Relative explosibility as a function of predicted relative explosibility