PYROCLOR

FIRE-RESISTANT
TRANSFORMER COOLANT BY **Monsanto**

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FIRE-RESISTANT TRANSFORMER COOLANT BY **Monsanto**

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Monsanto Chemicals Limited
10-18 Victoria Street
London SW1H 0NQ
Telephone: 01-222 5678
Telex: 916093

Monsanto Europe S.A.
Place Madou, 1
B-1030, Brussels, Belgium
Telephone: (02) 19.11.01
Telex: 22110/21986

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Introduction
History of Pyroclor

Over forty years ago electrical engineers expressed the need for a synthetic electrical insulating fluid to replace mineral oil for transformer installations where fire was a particular hazard. The new fluid had to be as good as mineral oil in every respect, in terms of electrical insulation properties and performance under working conditions. But it had to be fire-resistant.

This new synthetic transformer fluid was termed an "askarel" and like all chemical innovations underwent an initial period of acceptance. But gradually the askarel proved itself and its use is now widespread. In Europe askarel transformers form a large percentage of the distribution transformers installed today. In France, one-third of the distribution transformers brought into service each year are of the askarel type.

The first askarel fluid was produced by Monsanto in 1932 and was the ideal solution to many engineering problems. It meant that transformers could be placed indoors exactly where the electrical engineer wanted in his distribution system, at the load centre. Askarel-filled transformers could be sited in confined spaces and no maintenance would be required.

Askarel is a generic term for a group of fire-resistant products used as electrical insulating media.

Monsanto manufactures transformer askarel at their Newport, Monmouthshire, plant and the fluid is known as Pyroclor.

The purpose of this book is to enable both transformer manufacturers and transformer users to better understand the many benefits of Pyroclor in modern industry and to answer many of the questions which are still asked about transformer askarel.

An international specification for transformer askarels has been drafted and is being reviewed by the competent authorities of the various countries involved. It is intended that this international specification will form the basis of a British Standard. Manufacturers are assured that Pyroclor will meet or exceed this British Standard specification.

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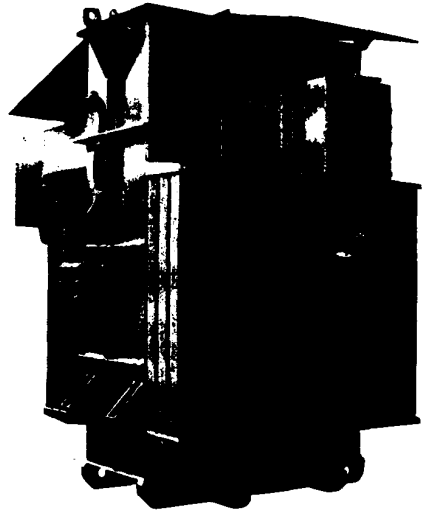
Pyroclor contains POLYCHLORINATED BIPHENYLS (PCB's) which some studies have shown may be persistent, an environmental contaminant and, possibly, injurious to certain forms of bird, aquatic and animal life.

However, the need for the safety and reliability provided by askarel-filled transformers, coupled with the fact that they are designed to be leakproof has enabled the continued use of PCB's in this application.

Two organisations in the electrical industry:—American National Standards Institute (Committee C-107) and C.I.G.R.E. (Study Committee No. 15 working group 02) are working to produce documents setting out guidelines/codes of good practice for the use of PCB askarels in electrical equipment.



A typical 1250 kVa 3300/433 Volts sealed Pyroclor-filled transformer.

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2 Uses of Pyroclor-filled Transformers

Pyroclor-filled transformers have been used in a very wide range of applications including installations in steel works, glass factories, airports, public buildings, offices and shops. In high rise buildings, Pyroclor-filled transformers have been installed several stories up or even on the roof, thereby saving valuable architectural space in overcrowded conurbations. In railways, ships, coal mines, oil refineries and chemical plants Pyroclor-filled transformers have provided fire safe installations, protecting both personnel and property.

Here, together with photographs, are a number of cases where Pyroclor-filled transformers are used by well known companies in many different industries.

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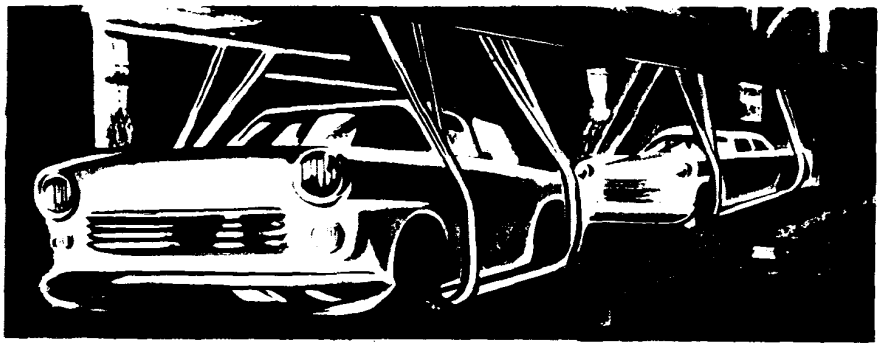

Automotive Industry

Fifty-three Pyroclor-filled Transformers on Motor Company Rooftops

Pyroclor-filled transformers solved a factory planning problem for the Ford Motor Co. Ltd. new tractor production plant at Basildon, Essex.

Although the plant covers 800,000 square feet the planners ruled that, in order to permit maximum flexibility in production layout, there should be no permanent obstructions in the floor area. This meant that the many transformers required to supply the manufacturing and assembly operations could not be placed inside the building at floor level. Owing to the immense size of the building, transformers sited externally would have meant long runs of expensive low-voltage cables to connect with the many load centres required. The obvious place was the roof.

But conventional transformers in this location would have meant an unacceptable fire risk—not so much from the possibility of a transformer itself starting a fire, but from the likelihood of it becoming involved in an extraneous blaze and its fluid carrying the fire to other parts of the building. Modern single-storey open-plan factories in fact constitute a major fire hazard since there are no solid walls to prevent the lateral spread of flames and smoke.

Nevertheless, the roof had undeniable attractions and Ford decided to carry on with the scheme using 11 Pyroclor-filled fire-resistant transformers.

In addition, 18 Pyroclor-filled transformers are sited at the Ford Motor Co. Ltd., Dagenham, works and 14 at the new car assembly plant at Halewood. All transformers are on the roof, so too are the 10 units at the Caterpillar Tractor Co. plant at Glasgow.

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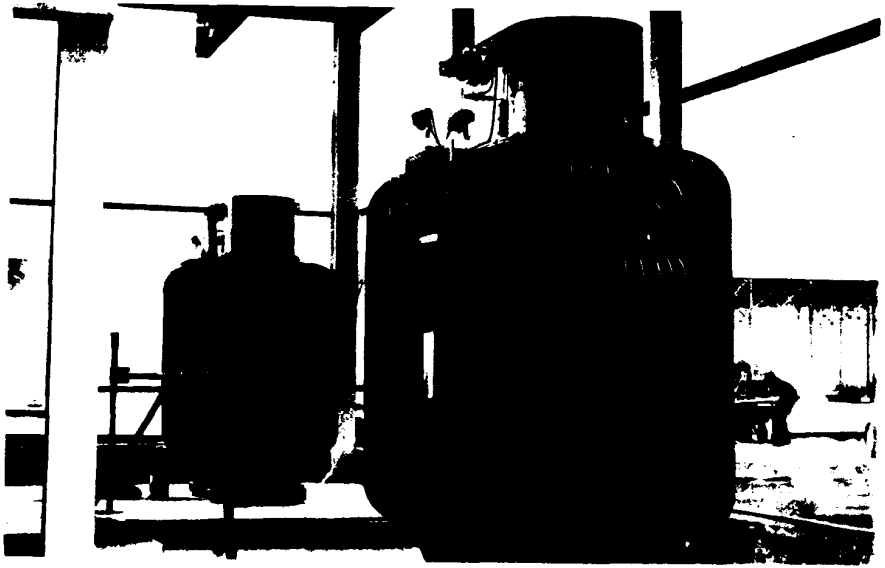
Roof installation—Two Pyroclor-filled fire-resistant transformers are installed on the flat roof of the Ford Motor Co. Ltd., Basildon Works, with a light enclosure around them. In the event of a fire in the factory below there is no risk of the transformer cooling fluid spreading the blaze.



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Pyroclor-filled transformers are supplying all power requirements at Vauxhall Motors' new 700 acre vehicle proving ground near Lidlington, Bedfordshire.

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Aviation Industry

Britain's First Jumbo Jet Hangar Powered by Transformers

Two 1.5 MVA transformers filled with Pyroclor are supplying all power requirements to Britain's first Boeing 747 hangar at Heathrow Airport, London.

Among unique features powered from the transformers are six sliding glass doors each 75 square feet and weighing 45 tons and an air conditioning system that blasts down an invisible curtain of hot air to bring the hangar temperature up to a comfortable 20° C (65° F) within 15 minutes of the doors closing, even in the coldest weather.

Besides natural light from a glass roof, a blended installation of 283 mercury and sodium lamps will provide pleasant working light for technicians maintaining the giant jets.

For servicing, aircraft will be towed into the hangar nose first and manoeuvred into a specially contoured steel mezzanine floor 16 feet above ground. This will allow access to wings, engines and forward fuselage. (In conventional hangars, movable steps and gantries are used.)

Another innovation powered via the transformers is the system for maintaining undercarriages. Normally, an aircraft has to be lifted up with jacks before the wheels can be moved, but in the new Hangar 01 the aircraft will remain on its normal level while the floor beneath the wheels is lowered to make inspection pits.

The periphery of the hangar, housing all ancillary buildings within 4-storey structures, will also receive all power requirements from the two transformers.

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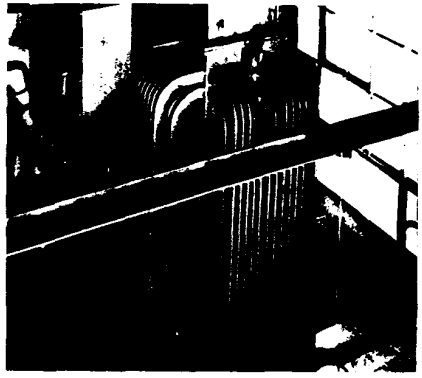
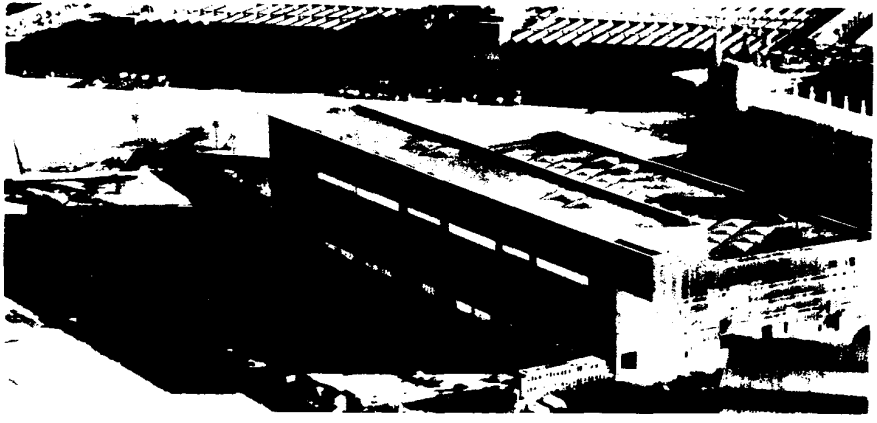
And whilst performing these many tasks, the Pyroclor-filled transformers will not require maintenance for at least 25 years. They were chosen because of safety, space and cost factors. Several hundreds of pounds a year will be saved because fire precautions are unnecessary and the transformers are load-centred, bringing further economies in installation layout.

The units are sited in a small transformer house in a corner of the Hangar and breakers of 800 amps feed into a bus bar circling the hangar's mezzanine floor with tap off points every two feet.



Right.—A 1000 kVA Pyroclor-filled transformer is installed at the Westland Aircraft Ltd factory in Yeovil, Somerset. To save space the transformer is located in the roof over a busy machine shop.

Below.—The new Jumbo Jet Hangar at Heathrow Airport, London. (Photo: courtesy Holland & Hannen & Cubitts (Southern) Ltd., and B.O.A.C.)



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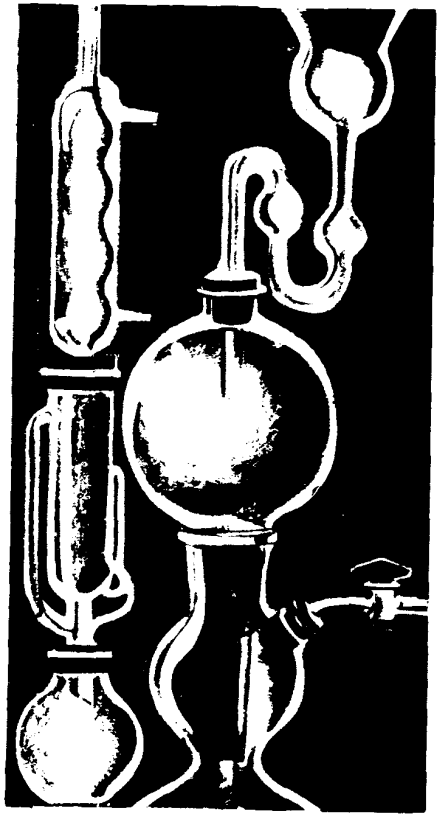

Chemical Industry

Low-Voltage Power Supply at Chemical Processing Plants

Some chemical processes involve the use of highly inflammable base materials. Large amounts of electric power may also be required, and the provision of suitable low voltage supplies under flameproof conditions can present problems.

At the Coleraine works of Monsanto Textiles Ltd., where Acrilan fibre is made, the necessary power is obtained from 8 x 1000 kVA (11 kV/415 V) and 6 x 500 kVA (11 kV/415 V) transformers. Four of the main distribution sub-stations are located in the main factory building. This location was made possible by the choice of Pyroclor-filled transformers which have reduced both installation and running costs.

At Baglan Bay, where Forth Chemicals Ltd. manufacture styrene monomer, the whole factory compound has been declared a flameproof area; consequently the 4 x 500 kVA transformers which supply the works are Pyroclor-filled even though they are sited out of doors. Similarly three 800 kVA and one 1500 kVA (11 kV/3.3 kV) and two 100 kVA (11 kV/415 V) transformers for the Monsanto polyethylene plant at Fawley have been located adjacent to the buildings involving ethylene processing.

In neither of these cases would it have been economical to use dry transformers, since these would have required protection from wind-blown dust and driving rain.

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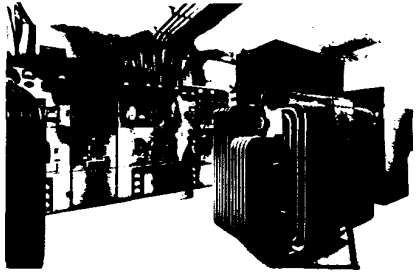

Pyroclor-filled transformers have reduced installation and maintenance costs at Monsanto Textiles Ltd., plant, Coleraine, N. Ireland.



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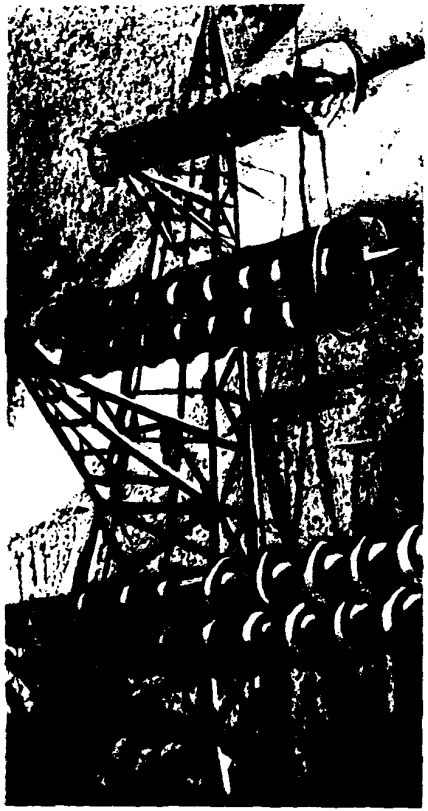

Electricity Generating Boards

Almost Twenty-Five Years Service in Electricity Generating Stations

The oldest transformers in Britain using Pyroclor are at Trafford, Manchester, power station of the Central Electricity Generating Board. Installed in a basement there as long ago as 1941, they are still in service. The units are of 500 and 800 kVA.

More recently, Pyroclor-filled transformers have gone into the San Esteban and Mallorca power stations in Spain, and in India, transformers of this type form part of the huge Damador Valley development in West Bengal, at the Bokara and Durgapur steam power stations.

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Installed in 1941 *and still in service— Pyroclor-filled transformers at Trafford Generating Station, Manchester*

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Pyroclor in "Excellent" Condition after 30 Years Service !

For 30 years two 1000 kVA transformers have been working in the sub-basement of the Birmingham Civic Centre, built before the war as the Town Hall. One of the transformers was taken out of service, because of re-development and re-distribution of load and it became possible to do a thorough examination of the Pyroclor fluid.

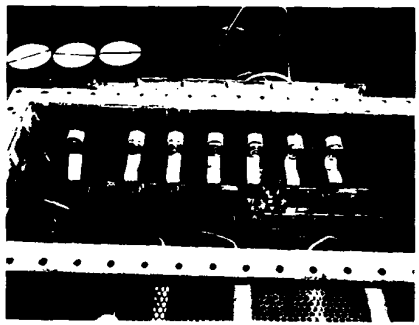
Samples of Pyroclor were taken from the top and bottom of the transformer and tested at Monsanto Technical Service Laboratories for electrical, physical and chemical properties. Results prove that Pyroclor is still in excellent condition and there is no evidence of decomposition after three decades of service.

Dielectric tests in accordance with BS 148:1959 (4 mm gap) showed that there was no breakdown of the fluid up to 90 kV. Modern transformers, unlike the one tested, are often hermetically sealed to prevent contamination by water. But tests on this unsealed transformer showed that the water content was only 52 ppm, substantially below the maximum level when drying out of Pyroclor is recommended.

Low acidity, low inorganic chloride content and the absence of carbon particles indicated the lack of decomposition over the years. Age had contributed to a slight increase in the boiling range of the Pyroclor, although not enough to affect the insulating properties.

Throughout their service life, these transformers (built to a specification dating back to 1936), have required no maintenance other than routine visual inspection. Nor have they required any topping up.

"Since the transformers were installed, records have either been lost or destroyed, but it is safe to assume that the Pyroclor was selected because of its fire resistant properties," said Mr. C. Claridge of the Birmingham Area M.E.B. who supervised the removal and examination of the pre-war transformer.



The top removed to show the clean condition of the interior.

And now, the 1000 kVA transformer will simply require topping up before it goes back into service at a suitable indoor location. Two more transformers of similar age are installed at Marshall and Snelgrove, the busy Birmingham store.

This is a remarkable example of the reliability of Pyroclor. What other insulating material would withstand 30 years of fluctuating load and still be in first-class dielectric condition? Or consider how many times a conventional transformer would have to be cleaned out and refilled over that period.

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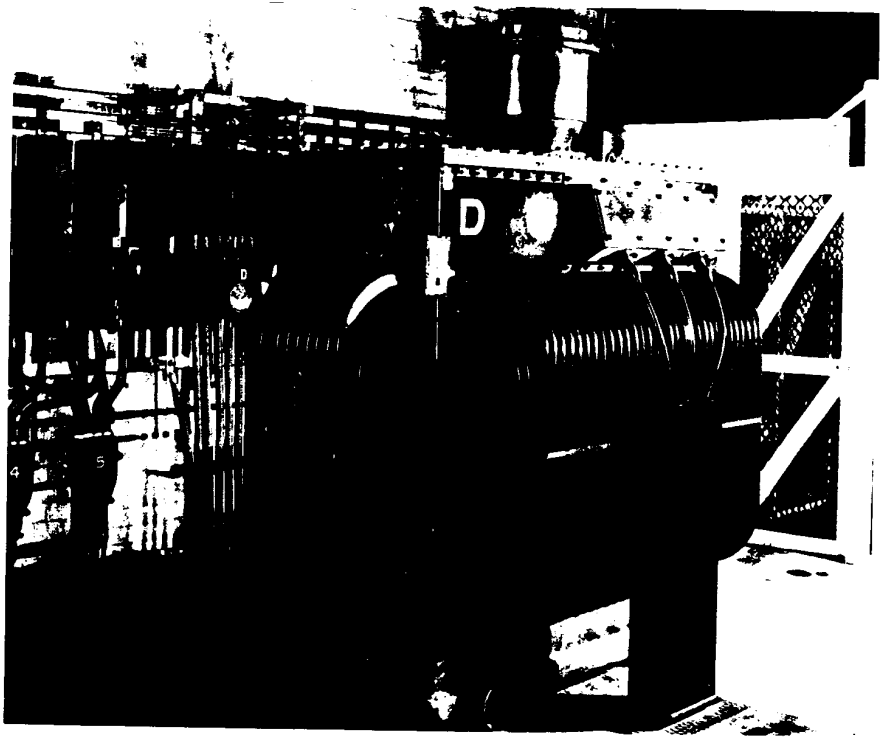
The 1000 kVA, 30-year-old Pyroclor-filled transformer at the Birmingham Civic Centre.



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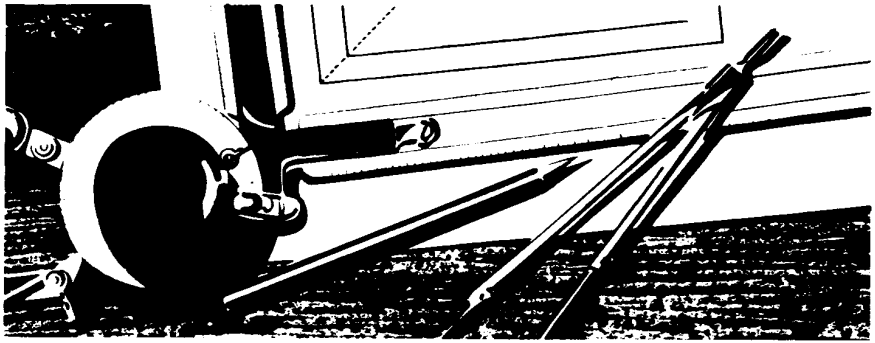

Engineering Industry

Analysing the Advantages of Pyroclor-filled Transformers in Package Sub-stations

When the choice has to be made between various types of transformers for a distribution system, the best analysis is to compare relative advantages.

This was the procedure adopted by Giddings & Lewis-Fraser Ltd, one of the world's leading manufacturers of numerically controlled machine tools. The total existing transformer capacity for the works was approximately 2,500 kVA installed in units of 500 kVA, and all transformers were of the oil-filled type having voltage ratios of 11,000/415.

Giddings & Lewis-Fraser Limited proposed installing an additional 750 kVA inside the factory to cater for the numerically controlled machine tools they manufacture, which are equipped with motors rated from 20-40 HP direct-on-line. It was decided that a package substation would show considerable cost and space savings compared with a conventional brick-built substation having a separate transformer connected by cable to the medium voltage switchgear. Only two types of transformer were considered: either Pyroclor-filled or Class "C" dry type. This was because of possible fire risk associated with oil filled transformers inside the factory and because of recommendations by the insurance company concerning fire risk.

And here are the various factors which were considered by Giddings & Lewis-Fraser Limited and which influenced their ultimate decision.

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Pyroclor Filled Transformer 750 kVA

Advantages

1. Fire-resistant insulant, consequently low fire risk.
2. No special buildings required for installation.
3. Compact and therefore suited to integrated transformer switchgear layout.
4. Can be placed at load centre resulting in large savings in cable costs which outweigh the additional cost of a Pyroclor-filled transformer.
5. Transformer hermetically sealed thereby preventing harmful ingress of dirt from a dust-laden atmosphere.
6. No fluid maintenance required.
7. Lower fire insurance rates.

Disadvantages

1. Possible long term efficiency of hermetic sealing unless a welded construction is used.

750 kVA Transformer Class "C" Insulated

Advantages

1. Air-cooled, consequently low fire risk.
2. No special buildings required for installation.
3. Compact and therefore suited to integrated transformer/ switchgear layout.
4. Can be placed at load centre but savings in cable costs would not outweigh additional cost of the air-cooled transformers.
5. Lower fire insurance rates.

Disadvantages

1. High cost: approximately 80% more than an equivalent-rated oil filled unit.
2. High risk of winding failure due to deposits of coolant vapour and cast-iron dust associated with machine shop atmosphere.
3. Maintenance cleaning problems associated with removing above deposits.

Pyroclor was the final choice and the finished package substation is a neat, compact arrangement. The medium voltage switch panels are fitted with 8 fuse switches TP & N, rated from 150 Amp. to 300 Amp. Future extensions can easily be accommodated on the switchboard together with cabling.



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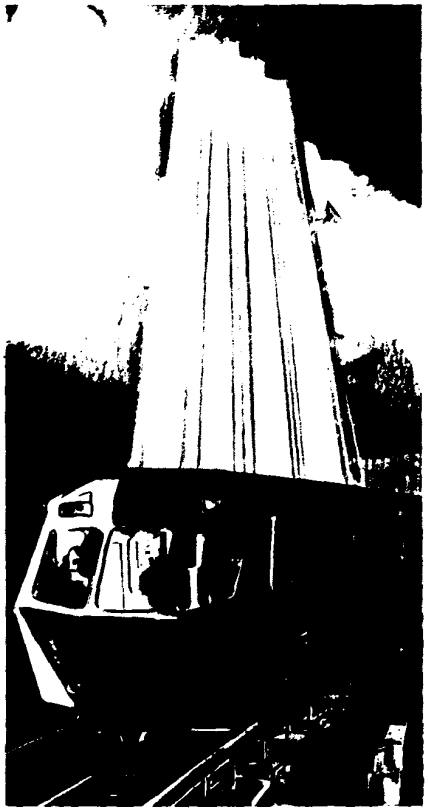

Exhibitions and World Fairs

EXPO 67

No less than 96 of the 100 electrical transformers used at Expo 67—Montreal's World Fair—were Pyroclor-filled. This architectural extravaganza with its 62 national pavilions created a high demand for electrical power to supply exterior illuminations, monorail systems and escalators, the Expo Express train service and for the massive displays designed around such themes as Man and his World and Man the Creator. Consumption of electricity during the exhibition period was rated as equivalent to a city with a population of 50,000 and the estimated cost including installations was £10,000,000.

Five single circuits at 25,000 volts nominal came from a substation on the south shore of the St. Lawrence river. Three of these circuits were transformed down from 25,000 to a 12,500 volt distribution network and the other two circuits were transformed down from 25,000 to a 600volts network for the various buildings and amusements.

Three double circuits at 12,500 volts from the north shore of the St. Lawrence river served directly electrical installations on Mackay Pier and the five rectifier stations of the mass transit system (Expo Express). These five stations were equipped with Pyroclor-filled transformers and rectifiers.

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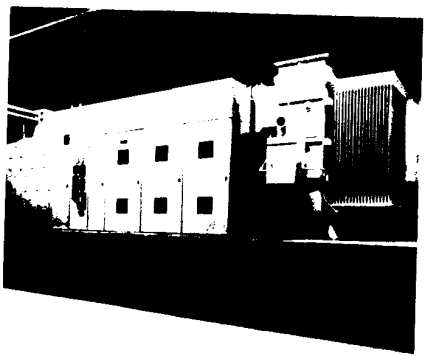



Illustrated here are the Pyroclor-filled transformers used for the British Pavilion and for the Expo Express rapid transit system.

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Gas Boards

The New Generation of Gas Works

The latest methods of town gas production are presenting plant designers with a number of new and interesting problems, derived from the inflammable nature of raw materials and from the large amounts of electric power required for the reforming process. A modern reforming plant may need up to 10 MW to drive motors for fans, feed pumps, hydrogen compressors, cooling tower pumps and other machinery. A further problem is space limitation. Most of the new plants must be erected on sites already occupied by coal-fed stations, and the latter cannot be removed until the new equipment is in full production. Both must operate together at first.

Finally, there is the question of reliability. The new installations usually comprise a number of separate gas-making units built into a common process. An electric power failure would halt the whole complex, and it might take several hours to bring a 120 million cu. ft./day output back on stream.

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The North Thames Gas Board's new plant at Slough, built by Woodall Duckham Ltd. on the site formerly occupied by a coal carbonising plant, will have an output of 80 million cubic feet of gas a day. Space was a critical factor, and the only way to fit three transformers into an area set aside for two was to specify 3 x 1500kVA Pyroclor-filled units to avoid the need for fire walls between and around them. They will work in parallel with automatic protection equipment; and should any of the three units fail the load will be automatically transferred to the other two. All are hermetically sealed and although their initial cost will be higher than equivalent oil-filled units, it is anticipated that maintenance costs will be lower.

On the same West London site, there is a 15-million cubic-feet-per-day peak load reforming plant which is fed with 1000 BTU methane gas. This plant is supplied with electricity from two 500kVA transformers which again are Pyroclor-filled, chiefly because a gas main runs across the only site available for the unit.

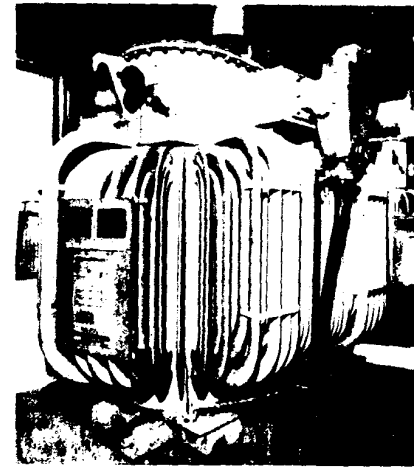
Pyroclor has the advantage of being chemically inert; it does not deteriorate in any way with time, consequently no maintenance is required and the initial charge of fluid should last for at least thirty years without replenishment or attention.

This was a factor in the choice of Pyroclor-filled transformers for the Slough Works and also for the new 120-million cubic-feet-per-day Town Gas Plant, Romford Works of the North Thames Gas Board. This is the largest capacity gas producing unit yet ordered by the British Gas Industry. Here there will be one group of 3 x 1000kVA and one group of 3 x 1500kVA Pyroclor-filled transformers on a site which may also have to be occupied by tanks containing light distillate spirit. The reformers in this plant are fully instrumentated and will be operated by a very small staff. It is therefore important that maintenance requirements should be kept to a minimum.

Other Gas Boards who have specified Pyroclor-filled transformers for reasons of space limitation and reduced maintenance are The North Western Gas Board at Preston where four 1500kVA units are in service whilst plant reconstruction is underway.

At the North Thames Gas Board, Southall, Europe's largest gas plant, two 600kVA Pyroclor-filled transformers have been operating since 1958. Pyroclor-filled transformers were chosen because of possible fire hazard and drainage pit considerations if conventional oil-filled units had been used. Furthermore, problems of space and cost precluded the use of air-cooled transformers.

Pyroclor-filled transformers at the North Thames Gas Board, Southall, have operated successfully since 1958.



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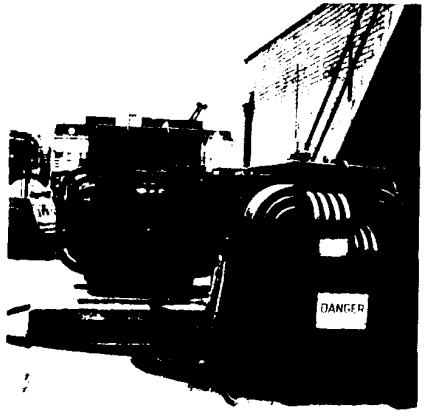
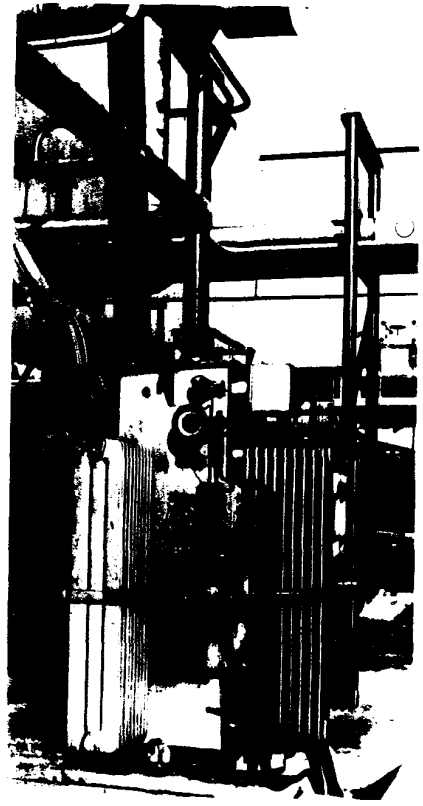
One of the four 750 kVA hermetically sealed Pyroclor-filled transformers installed in a flame-proof area at the North Thames Gas Board Canvey Island Methane Terminal, in close proximity to the liquid methane tanks. These transformers are manufactured to B.S. 171 and operate at 3300/415 volts. The low tension cable box is pressurised with nitrogen and there is a flame-proof cable box on the high tension side. The transformers are fitted with temperature gauges and bursting discs.

Pyroclor-filled transformers located at North Thames Gas Board, Slough.





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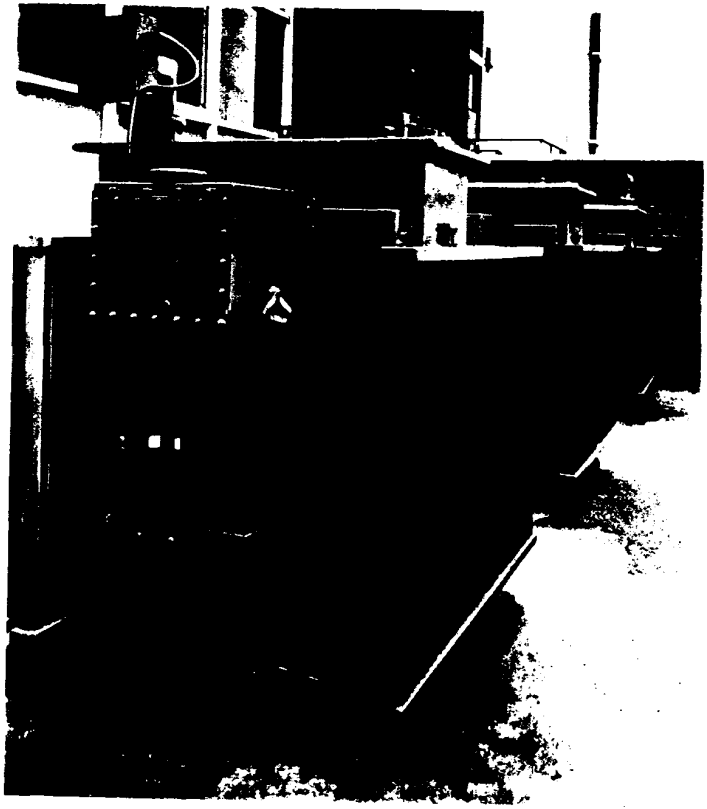

Pyroclor-filled transformers associated with the power supply to the large-scale production plant of the North Thames Gas Board, Romford. They are installed in close proximity to highly inflammable spirit tanks.

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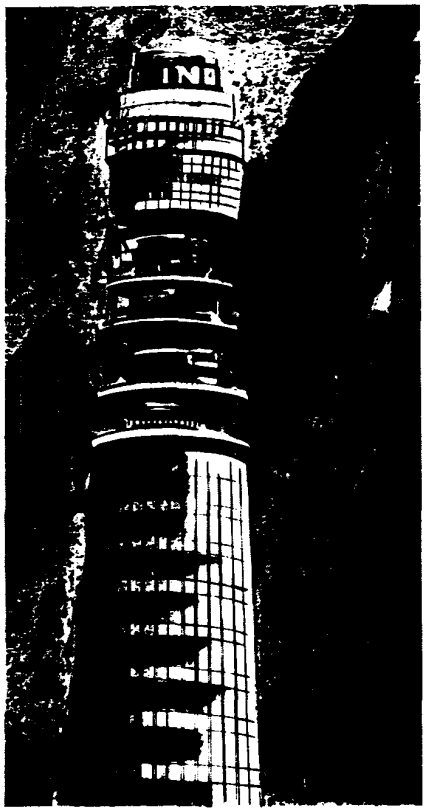

General Post Office

Compact, Dust Free, Pyroclor-filled Units Below Ground for Railway Power

Recent modernisation on the British Post Office's private underground railways, which link eight postal depots in the busiest parts of London, included the installation of Pyroclor-filled fire-resistant transformers.

In the event of the transformers becoming heated due to a fire in the vicinity there is no risk of burning fluid spreading the conflagration through the underground tunnel systems. For static rectification of alternating current, the combination of Pyroclor-filled transformers and mercury-arc rectifiers has proved extremely reliable and economic.

At Mount Pleasant the sub-station is below the platform on which the mail-bags are handled. Pyroclor-filled transformers were chosen because no enclosures or CO_2 equipment were required. They were preferred to air-cooled units because they are more compact, an important consideration below ground. In Lisbon, Portugal, the Metro has installed seven Pyroclor-filled transformers for a sunken rectifier sub-station and The Pennsylvania Railroad Co. has now used Pyroclor-filled units for 25 years. Every one of the company's 215 electric locomotives is now equipped with this type of transformer.

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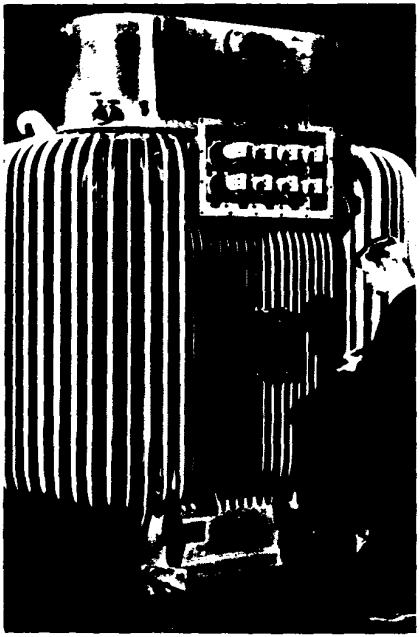

A Pyroclor-filled transformer of the type used by the British Post Office at its Mount Pleasant, London, sorting office.



At the Post Office private underground railway, power for traction, signalling and lighting comes from transformers filled with Pyroclor fire-resistant cooling fluid.

0102837

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Glass Industry

Where large numbers of transformers are required for different duties as, for example, in a modern glass works with electric furnaces and electrically driven machinery, L.T. cable costs can become astronomical unless the transformers can be sited close to the equipment they are to serve. This often means that only Pyroclor-filled fire-resistant transformers can be considered for most duties, and at Chance-Pilkington Optical Works, St. Asaph, N. Wales, a total of 19 such units have been installed.

Four 750 kVA transformers are the main source of power, with 15 special transformers and reactors, to supply the various furnaces. The latter include 1 x 200 kVA, 5 x 150 kVA, 1 x 100 kVA, 6 x 50 kVA and 2 x 37.5 kVA units. All are located at load centres inside the factory itself and the use of Pyroclor has saved fire protection costs, reduced maintenance and by far the greatest saving has come from the reduced lengths of L.T. distribution cable required.

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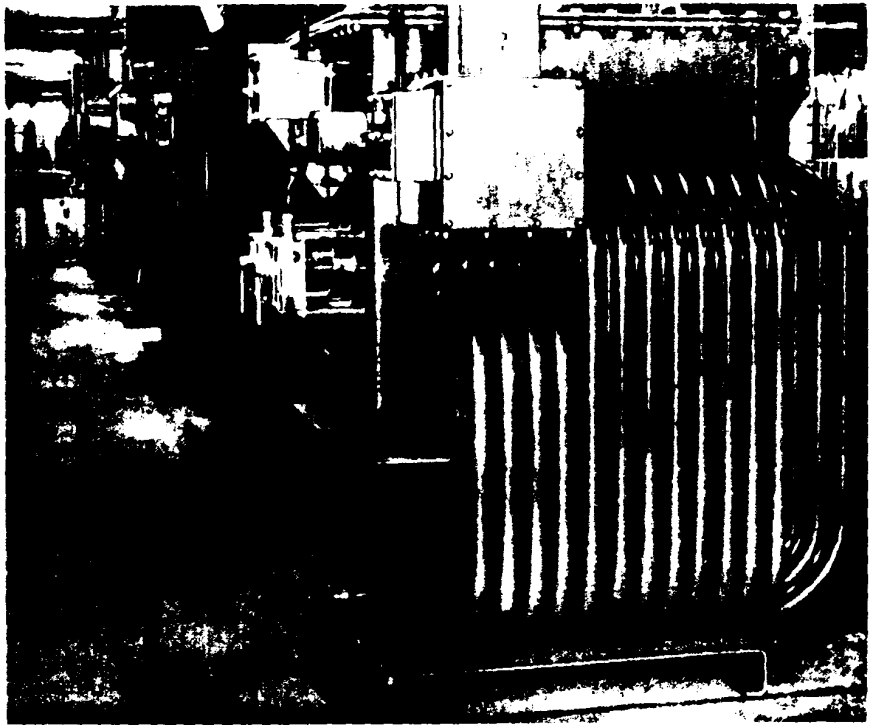
Large numbers of Pyroclor-filled transformers performing various duties at the Chance-Pilkington Optical Works, St. Asaph, N. Wales.



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Multi-Storey Buildings

Freedom from Fire Risk in High-Rise Structures

Pyroclor-filled transformers are ideal for supply services in tall buildings. Freedom from fire risk is important in overcrowded areas and these transformers can be sited anywhere, in the basement or at the bottom of a lift shaft, for example, without special fire protection.

Costly runs of L.V. cable are avoided by using Pyroclor-filled transformers in the sub-stations on several levels of a tall office block. The clean lines and modern appearance of present-day architecture are not marred by obtrusive out-buildings or cages. Pyroclor transformers can be installed indoors, out of the way, and assist improved architectural planning.

The Canadian Imperial Bank of Commerce, Montreal, installed Pyroclor-filled transformers on the 42nd floor, further proof that these units can be safely installed anywhere—even at the top of the Commonwealth's tallest skyscraper!

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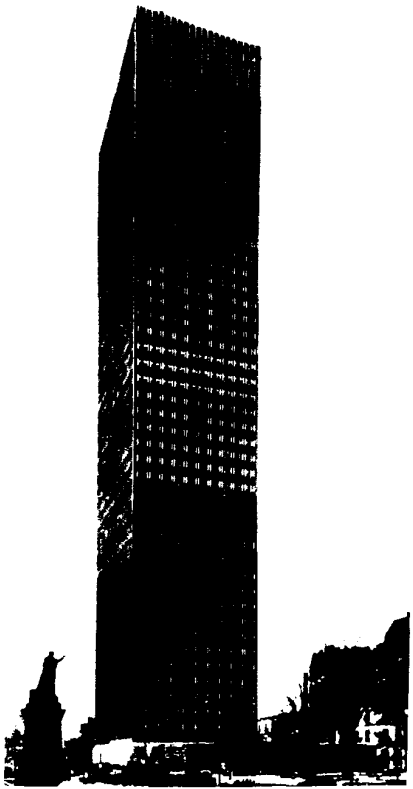
An interior view of the sub-station at the Canadian Imperial Bank of Commerce.



Pyroclor-filled transformers have been installed on the 42nd floor of the Canadian Imperial Bank of Commerce, Dominion Square, Montreal, Canada.

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National Coal Board

Several modern colliery winding installations in Britain have been equipped with Pyroclor-filled fire-resistant transformers.

In the event of the transformers becoming heated due to a fire in the vicinity there is no risk of burning oil pouring down the mine shaft to spread the conflagration.

The North Western Division of the National Coal Board, for example, has installed 14 Pyroclor-filled transformers for rectifier duties at collieries in the Lancashire area. These are installed in the winding towers immediately above the pit shafts and, according to an NCB official, "the fire hazard associated with the difficulty of containing such a large volume of oil from reaching the shaft, made it essential to use a non-flammable fluid if the transformers were to be mounted in this position and avoid long and costly copper connections". Very similar installations have been completed at two collieries in the Durham Division of the National Coal Board.

0102843

TOWOLDMON0022311



Oil Industry

In Oil Pipeline Systems

With completion of a new 500-mile pipeline by Constructors John Brown Ltd., over the Atlas mountains, from the Sahara Desert to the Mediterranean coast, a further 10 million tons of crude oil a year will flow from the Algerian oilfields of Société Nationale de Transport et de Commercialisation des Hydrocarbures (S.O.N.A.T.R.A.C.H.).

At the Arzew terminal on the Mediterranean, where light crude oil is stored ready for loading into sea-going tankers, a 500 kVA Pyroclor-filled transformer has been placed beside the main switchroom. Two more, one of 150 kVA and one of 200 kVA, have been installed at a nearby tanker deballasting station and in the maintenance workshop.

The advantage gained by installing Pyroclor-filled transformers was the freedom from fire risk when pumping a light crude oil at ambient temperatures which may vary between −2°C and +50°C. By minimising this risk it was possible to obtain better insurance rates and to conform with the practice in Algeria, where all existing oil plants have transformers with fire-resistant filling.

All units supplied for the S.O.N.A.T.R.A.C.H. project are hermetically sealed and will require little maintenance—a factor of some importance where unskilled staff are being trained to take over. And because the transformers were sited close to the plant long cable runs have been avoided.

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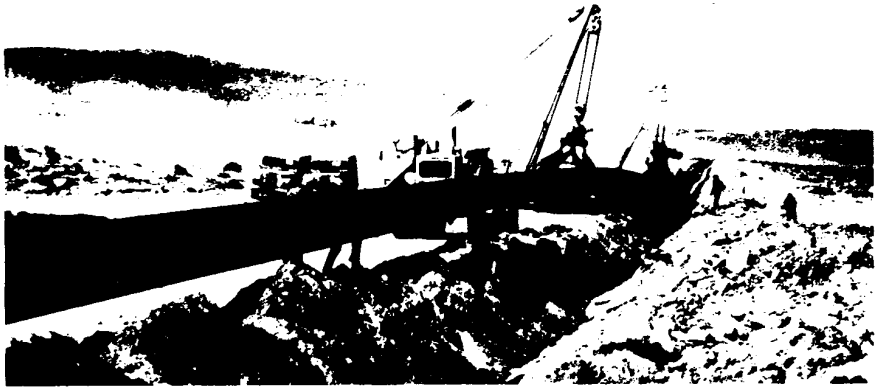
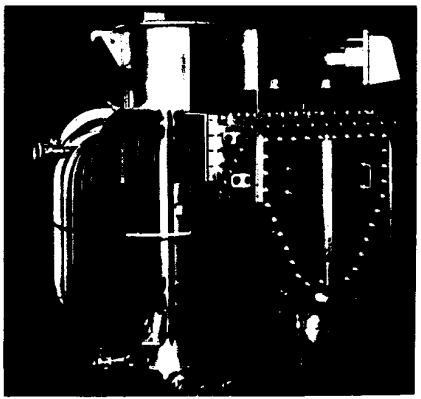


In the Sahara Desert, Pyroclor-filled transformers for the 500-mile S.O.N.A.T.R.A.C.H. oil pipeline installation.



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Rubber Industry

In Motor Tyre Factories

As in many other modern factories it is important to locate distribution transformers close to the plant they serve and to eliminate the expense of low-tension cable runs. But if the factory has a fire hazard, as in a large motor tyre plant, such economies are impossible to achieve unless Pyroclor-filled transformers are specified.

At the Goodyear Tyre & Rubber Company's works in Glasgow, electric power and lighting demands are met by one 1250 kVA and four smaller transformers, all sited inside the factory buildings. Three have been installed in major control rooms and the other two on platforms high above the production shops. The aim in choosing these sites was to place transformers as close as possible to the various load centres without encroaching on valuable production space at floor level. This was made possible by using Pyroclor-filled transformers.

The main transformer installation at the Belfast factory of Michelin (Belfast) Ltd., is oil filled. Even so, the six 40 kVA transformer/transductors, six 50 kVA transformers and four 100 kVA transformers on the shop floor, where the fire hazard is greater, are filled with Pyroclor.

Pyroclor-filled transformers are also used at the Firestone Tyre factory, South Africa. In countries where higher ambient temperatures are experienced, the high thermal stability of Pyroclor is an added advantage which has contributed to its general use in such areas.

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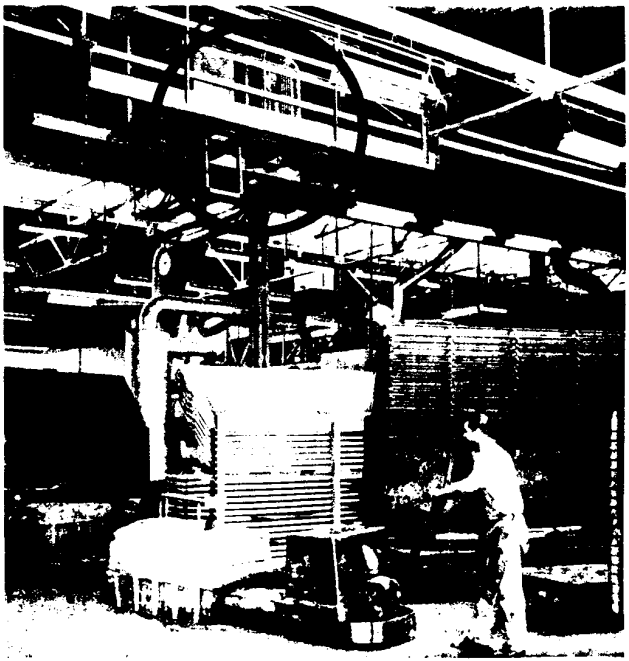
Saving space on the factory floor with Pyroclor-filled transformers mounted in the roof girders at Goodyear Tyre & Rubber Co. Ltd.



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Steel Industry

Basement Locations in Steelworks Eliminate Fire Hazard

At the world's most advanced steelworks, the Spencer Works of Richard Thomas & Baldwins in South Wales, Pyroclor-filled transformers are installed in the basement of one of the rolling mills to eliminate fire hazard. The basement houses part of the main power distribution and control systems and even minor damage there could result in complete plant stoppage.

Two Pyroclor-filled transformers supply rectifiers providing direct current for the main drive motors of the two 60-inch temper mills which give the final finish to the cold-rolled wide strip. These 11 kV transformers are rated at 2625/4280 kVA.

This installation is only one of several completed in recent years in British steelworks. The Steel Company of Wales, at its Port Talbot Works, uses three Pyroclor-filled transformers for the 56-inch high-speed temper mill, and the Appleby-Frodingham Steel Company, at Scunthorpe, has 11 units, supplying mercury-arc rectifiers.

In all these three installations, in basement locations, air-cooled transformers with the British Class H insulation (180° C.) were considered but Pyroclor was preferred on cost grounds and because of the dusty environments. The modern steelworks depends on an unfailing supply of electricity. Even if a minor fire damaged the power distribution system this could have far-reaching repercussions.

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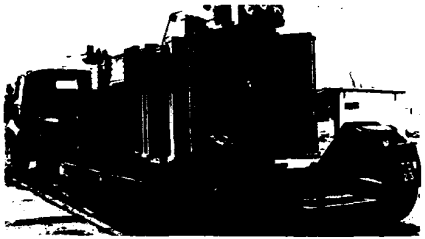
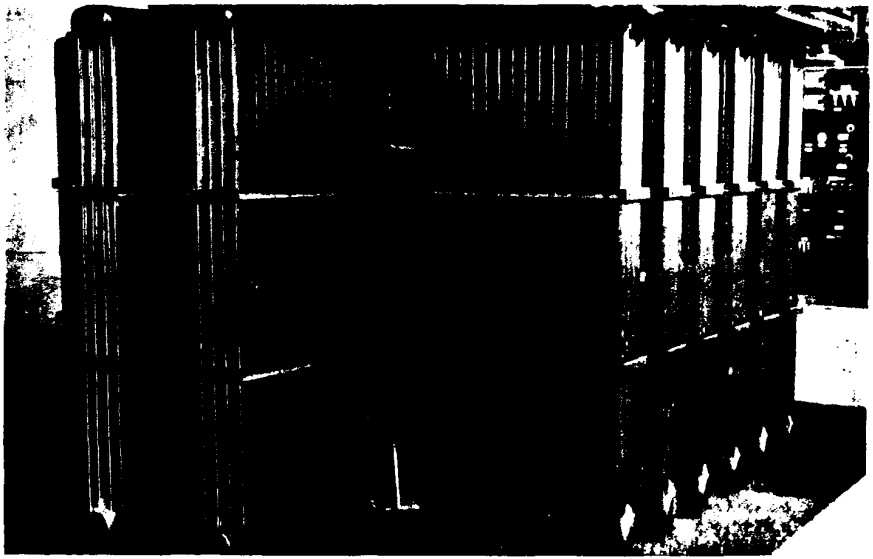


Left: Pyroclor-filled transformers en route to Steel Company of Wales.

Below: Pyroclor-filled transformer units at Richard Thomas and Baldwins Ltd.



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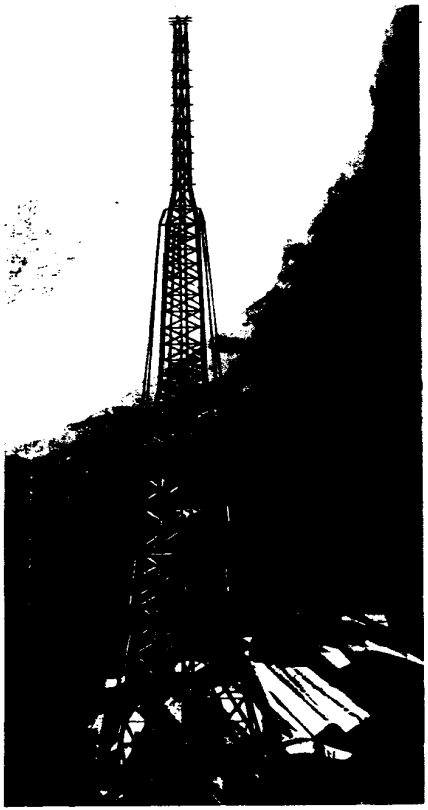

Television

Pyroclor-filled Transformers in high ambient Temperatures

Pyroclor-filled transformers are now in service at the new national television station for Malaysia. They are rated at 3,750 kVA, 11/3.3 kVA, and connect with a series of smaller Pyroclor-filled transformers—2 x 1,000 kVA, 1 x 750 kVA and 1 x 500 kVA at 415 volts. Package sub-stations are used for these smaller units, built in the form of control panel consoles.

Despite their size, these 3,750 kVA Pyroclor-filled units form a neat indoor installation with control gear alongside, as illustrated. The Pyroclor fluid is unaffected by high ambient temperatures associated with tropical areas and the transformers are sealed, as recommended when using Pyroclor, so that maintenance is eliminated completely. Hence, there is always trouble-free transformer activity, an important consideration for ensuring continuity of television programmes.

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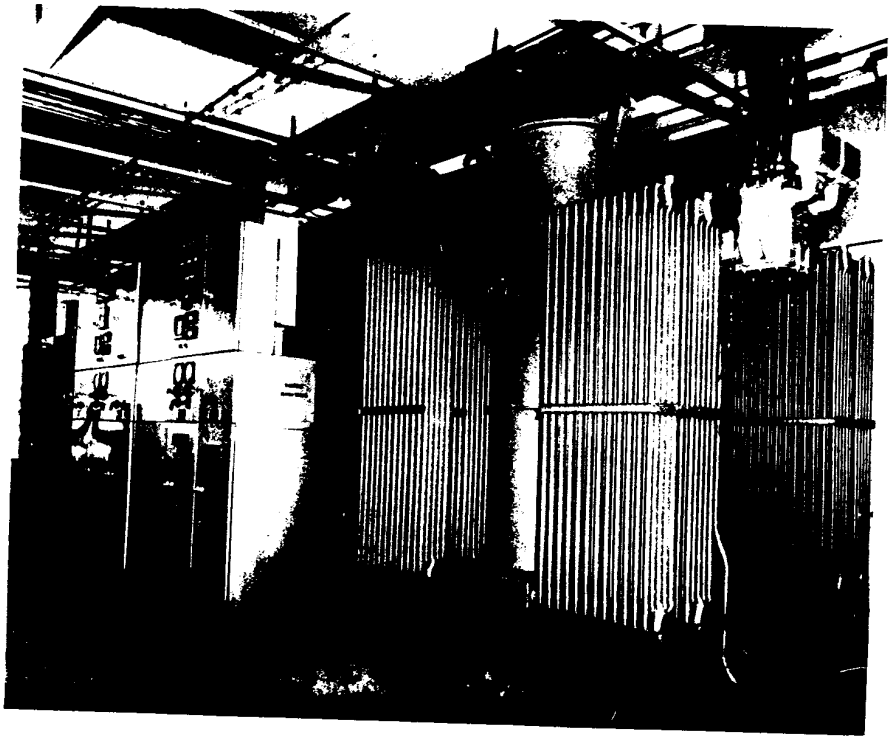

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3
Advantages of Pyroclor-filled Transformers

Pyroclor-filled transformers are intended primarily for medium voltage distribution systems from 50 kVA to 2,000 kVA. The electrical engineer has a choice when designing such systems between three types of transformer unit:

Oil-cooled

Air-cooled (Class C)

Pyroclor

Following are some of the reasons why Pyroclor-filled transformers are often considered in preference to the conventional oil-filled or "Class C" dry-type transformer.

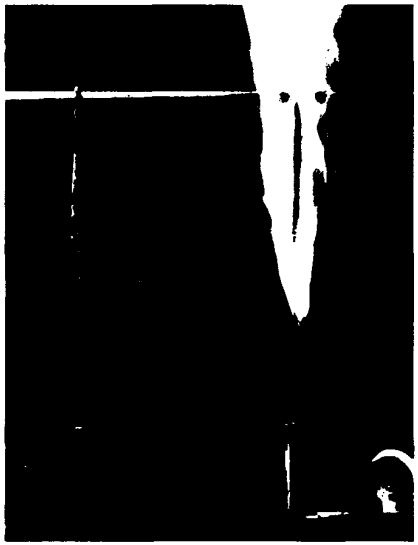

Figure 2 flame test for Pyroclor—
the oil-soaked material on the right burns rapidly while the material soaked in Pyroclor on the left will not ignite under a bunsen burner.

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Fire resistance

Pyroclor is very fire-resistant. It cannot be ignited by internal transformer arcing or by surrounding flames and therefore provides maximum transformer safety.

No Fire Precautions

Pyroclor-filled transformers eliminate the need for fire walls, pebble drains and fire fighting equipment.

No siting limitations

Pyroclor-filled transformers are particularly suitable in many applications where fire risk is great and space is limited. They can be located indoors, close to working areas or at the load centre. Increasing population, higher density of building and proliferation of industrial plants, high rise offices and apartments have put a high cost on space. The electrical engineer faces problems of reduced architectural space. Tight cost control has set a premium value on construction economies and reduced operational costs. These limitations present a number of difficult problems in system design for the electrical engineer. "Load centring" has emerged as a means of solving them. In load centring, Pyroclor-filled transformers, long-established and thoroughly service-proved can provide new solutions—reducing expensive low voltage cable runs and improving voltage regulation.

Freedom from contamination

This is particularly important when transformers are being installed while building construction is in progress. Sealed Pyroclor-filled transformers are unaffected by dirty or dusty atmospheres.

Over-voltages

Pyroclor-filled transformers can be used in installations where over-voltages due to lightning or switching surges are prevalent.

Low noise levels

A comparison of various noise levels is tabled for Oil-filled, Air-cooled and Pyroclor-filled transformers. Pyroclor-filled transformers are the quietest in operation across the complete kVA range and for guidance 50-60 decibels represent the noise of suppressed conversation in a business office whereas 60-70 decibels is equivalent to a radio at high volume. The decibel range of noise measurement is an exponential progression. Hence a "7" decibel noise increase represents a noise seven times as loud.

Comparison of Noise Level

Size kVA	Oil-Filled Decibels	Air-Cooled Decibels	Pyroclor-filled Decibels
500	54	58	53
750	56	60	54
1,000	57	62	55
1,500	59	64	57

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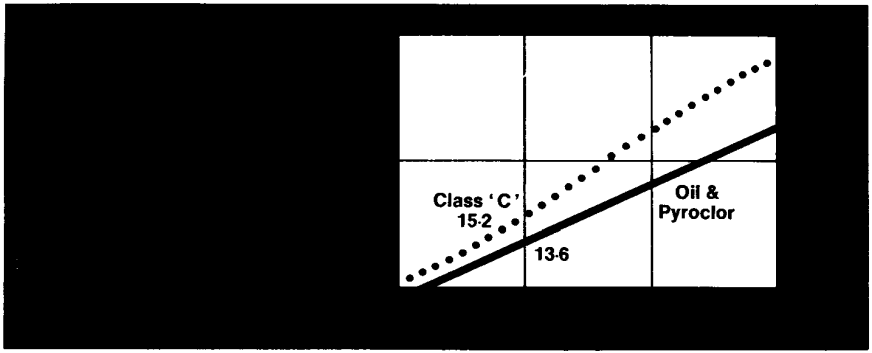
Low Power Loss

Loss levels are another important consideration. In the graph below, the losses of Oil-filled and Pyroclor-filled transformers are identical whereas the loss level of Air-cooled transformers is consistently higher.



Iron core and copper core losses for the three alternative types of transformer are given in detail in this table:

Comparison of Power Losses

Size kVA	Iron Core Loss (Watts)		Copper Core Loss (Watts)	
	Dry-Type (Class "C")	Oil-Filled or Pyroclor-filled	Dry-Type (Class "C")	Oil-Filled or Pyroclor-filled
300	1,200	673	6,250	4,600
500	1,480	1,030	8,050	6,860
750	1,900	1,420	10,400	9,500
1,000	2,400	1,770	12,800	11,820
1,250	2,950	2,150	15,500	14,000
1,500	3,480	2,400	18,500	16,000
2,000	4,375	3,000	25,000	20,000

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High impulse level

Pyroclor-filled transformers (built to BS.171) have high impulse strength and offer a greater margin of safety against surging and overload than Class 'C' transformers.

No maintenance

Because Pyroclor is blended to provide maximum thermal and chemical stability, a *properly sealed* Pyroclor-filled transformer requires no maintenance. No fluid checks, fluid filtration or fluid change should be needed for the entire life of the Pyroclor-filled transformer, see page 70.

Maximum reliability

Pyroclor-filled transformers are as sturdy and reliable as oil-cooled units. A statement of their reliability by a large network user is given as follows:

"Properly designed and installed askarel-filled transformers will give trouble-free service for over 30 years. Since their introduction in 1932, the overall failure rate has been less than 0.5% for all units under test and service conditions."

Ideal for Package Substations

The fire-resistance and elimination of fluid maintenance benefits make Pyroclor-filled transformers particularly suitable for package substations where connections between transformer and switchgear may be solid busbar, thus eliminating the need for M.V. cable. Overall cable costs, site labour charges for interconnecting and time for installation are also greatly reduced. Busbar interconnections also lower the chances of a fault. Floor-space is saved, and the package Load Centre can be neat and uniform.

Lower Insurance Premiums

Although there is no standard reduction of premiums by insurance companies for Pyroclor-filled transformer users, many companies have been able to negotiate lower insurance premiums.

Summary of Main Benefits of Pyroclor-filled Transformers

No pebble drains & fire eq.	OIL	air	PYROCLOR
No maintenance		✔	✔
No siting limitations			✔
Low noise levels	✔		✔
Low loss levels	✔		✔
High impulse levels	✔		✔
No fire risk		✔	✔

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4
Cost saving with Pyroclor-filled Transformers

Typical installed costs of Pyroclor-filled, mineral oil-filled and Class 'C' transformers, based on equivalent rated transformers have been calculated. While the initial cost of a mineral oil-filled transformer is lowest, once provision has been made for maintenance, re-filling and the fire precautions almost certainly necessary with a flammable liquid, the installed cost can well be even higher than that of a Class 'C' dry-type. The Pyroclor-filled transformer, whose initial cost is between that of the other two, can prove to be the least expensive.

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In a well constructed transformer, the initial Pyroclor charge can be expected to last the life of the transformer. Thus a Pyroclor-filled transformer is maintenance free under normal operating conditions. Maintenance must be carried out on both oil and dry-type transformers. The following table gives details of typical maintenance requirements and costs.

Source of Cost*	OIL	AIR CLASS 'C'	PYROCLOR FILLED
Transformer 1000 kVA	58	110	82
Fire-protection equipment	32	—	—
Civil Work	10	8	14
TOTAL	100	118	86

Type	Work Required	Frequency
OIL-FILLED Cyclic Loading	Oil Filtration Oil Change Sample Check	Every 7 years Every 14 years Every year
Continuous Load	Oil Filtration Oil Change Sample Check	Every 4 years Every 8 years Every year
OPEN DRY-TYPE (Class "C")	Regular cleaning of air gaps and air ways	Depending upon environment, but at least once annually
PYROCLOR-FILLED	NONE	—

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Examples of Cost Savings with Pyroclor-filled Transformers

The most impressive savings that Pyroclor-filled transformers can make are in the total solution of the power distribution design problem. The following are two typical problems with their alternate solutions compared.

EXAMPLE 1 (Theoretical)

Small factory, 200′ × 400′, requiring installed capacity of 1,000 kVA, supplied at 11 kV, and distributed at 415 V.

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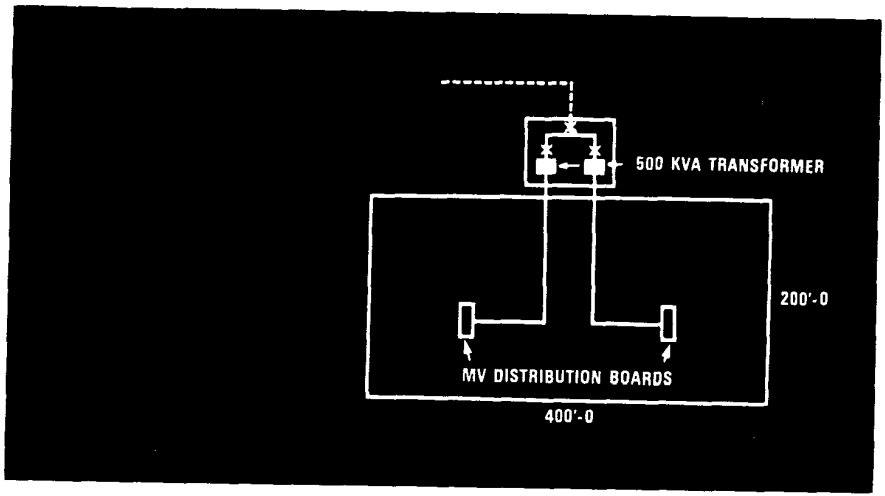

Two 500 kVA transformers in outside sub-station, feeding two indoor distribution and starter boards inside.

Cable Costs

MV Cable:

0.6 sq. in. Copper (P.I.L.C.W.P.V.C.) (singles)	£ 2,227/1,000 yds
0.8 sq. in Aluminium (singles) (P.V.C.) (Assume 4-core M.V. cable required)	£ 888/1,000 yds

Solution A Requires:

200 ft. MV cable between each transformer and distribution board.

$2 \times 200 \times 4$ (cores) = 1,600 ft.

$\frac{1,600}{3} \times$ £ 2,227/1,000 (Copper) = £ 1,190

$\frac{1,600}{3} \times$ £ 888/1,000 (Alum.) = £ 474

Note: All pricings quoted are based on costs prevailing 3rd quarter 1967.

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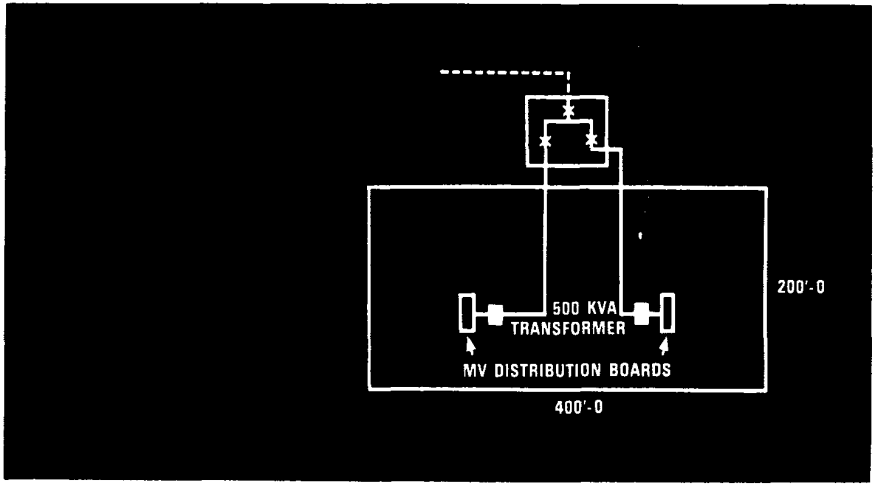

Site two 500 kVA transformers inside building with distribution boards.

Cable Costs

E.H.V. Cable:

0.06 sq. in. Copper (P.I.L.C.S.W.A.)	£ 1,342/1,000 yds.
0.10 sq. in. Copper (P.I.L.C.S.W.A.)	£ 1,837/1,000 yds.
0.15 sq. in. Aluminium (Sat. polythene S.W.A. & P.V.C.)	£ 1,838/1,000 yds.

(Prices are for 3-core cable)

Solution B requires two 200 ft. E.H.V. cable runs to connect source of supply to the indoor transformers.

$200 \times 2 = 400$ ft. E.H.V.

$\frac{400}{3} \times$ (Costs cited) = £ 179 (0.06 Copper)
£ 245 (0.10 Copper)
£ 245 (0.15 Alum.)

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TOWOLDMON0022328

Operating Costs

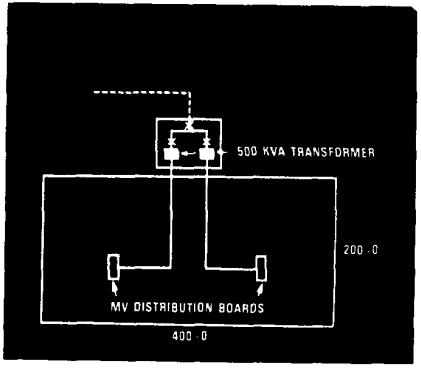
Assume the two transformers are 75% loaded, 50% of the time, operating 4,400 hrs/annum, with power costs at ½p./unit.

(Solution A) Power Loss in MV Cable	(Solution B) Power Loss in E.H.V. Cable
6,100 watts (Copper) 7,750 watts (Alum.)	66 watts (0.06 Copper) 40 watts (0.10 Copper) 44 watts (0.15 Alum.)

The minimum improvement in conductor loss by using the E.H.V. cable to a load centre is 6.03 kW or an annual minimum saving of £110

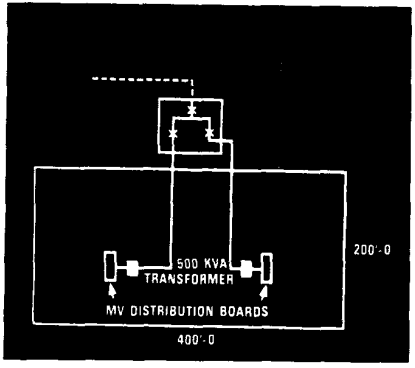
Cost Comparison Summary

1,600′ MV Cable



Cable Cost: Minimum Saving £ 229
Operating Cost: Minimum Saving £ 110 per annum

400′ E.H.V. Cable



A short check will show that the savings could be as great as £ 1,100 annually, approximately 65% of the initial cost of the Pyroclor-filled transformers.

TOWOLDMON0022329

EXAMPLE II

(Actual case history detailed cost analysis of installation and operation*).

Factory with fire risk. Transformer size 1,000 kVA; maximum demand, 700 kVA; load factor, 0.35.

Three alternative solutions of the problem of supplying this can be considered:

1

Substation to be installed outside factory with MV feed to load centre—a distance of 200 yds.

(Cost: £6,688)

2

Substation to be installed inside factory at the load centre containing a standard oil-filled transformer and MV switchgear. Fire protection equipment to be installed inside the substation. The 11 kV metering O.C.B. to be installed outside the factory a distance of 200 yards away.

(Cost: £2,891)

3

Same as 2 but utilising a Pyroclor-filled transformer; no fire protection needed.

(Cost: £2,623)

The costs that would be common to all solutions can be omitted. The electrical characteristics of Pyroclor and oil-filled transformers are similar, therefore the cost of transformer losses can be ignored.

Basic Pricing Data

Cable Losses:

Based upon C.E.G.B. bulk tariff

Day rate units (adjusted for 100/- per ton of coal) 0.6873 d/unit

Peak units (adjusted for 100/- per ton of coal) 1.0873 d/unit 90% of the losses occur at the Day Rate

10% of the losses occur at the Peak Rate

Therefore, cost per unit (plus 5% to cover losses in the system) is:

$0.6783 \times 0.90 + 1.0873 \times 0.10 \times 1.05$ d/unit = 0.7688 d/unit

Demand Costs:

(including 8% to cover losses in the system) = £7.11/kW

Loss Load Factor:

$0.3F + 0.7F^2 =$ 0.191
(where F = load factor (0.35)

* Grateful acknowledgement is made to the Birmingham Electrical Engineering Dept., Midland Electricity Board, for their assistance in calculating this case history

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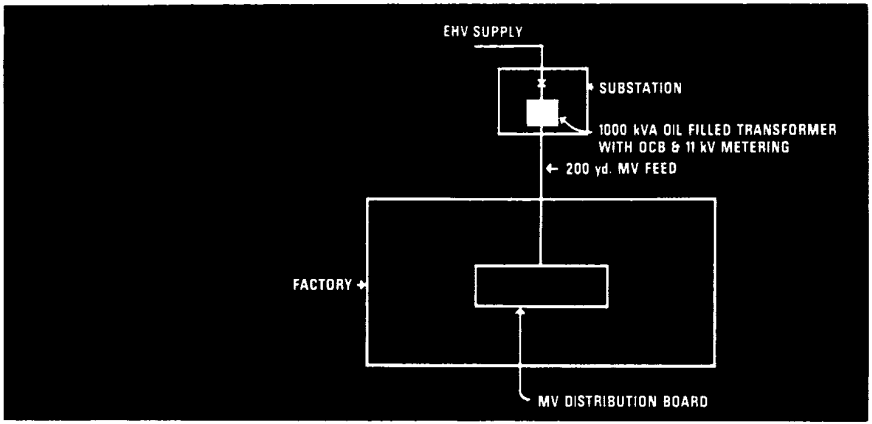

System Conditions:

Cables installed in conduits: 700 kVA = 970A
(Rating of 3 × 4C .5 Al. cables installed in a 3-way conduit is 370 A—in accordance with ERA Report Reference F/T.183).

Voltage Conditions at Load Centre:

Assumed temperature of cables: 50°C
Resistance of 4C .5 Al. cables at 50°C = 0.084 × 1.121 = 0.094 ohms/1000 yds
Load on each cable $\frac{970}{3}$ = 323A

Volt Drop along 200 yd. length: $323 \times \frac{200}{1000} \times 0.094 =$ 6.1V (2.5%)

Capital Costs:

	£
Additional cost over alternatives to house switchgear and transformer	100
Oil-Filled Transformer	1,100
3 × 200 yds, 4C .5 Al. cable supplied, delivered and installed (including cost of conduits) and terminated	2,700
	3,900
On cost 8%	310
Total:	**£4,210**

Cost of Operating Losses:

I^2R per cable $323^2 \times 0.094 \times \frac{200}{1000^2} \times 3kW$
= 5.9 kW per cable
Annual unit losses in one cable: $5.9 \times 8760 \times 0.191 \times \frac{0.7688}{240} =$ £31.5
Demand Losses per cable: 7.11 × 5.9 = £42
Total annual losses per cable: £73.5
Total losses per 3 cables: £220.5
Loss over 25 years at interest of 7½%: £220.5 × 11.147 = **£2,478**

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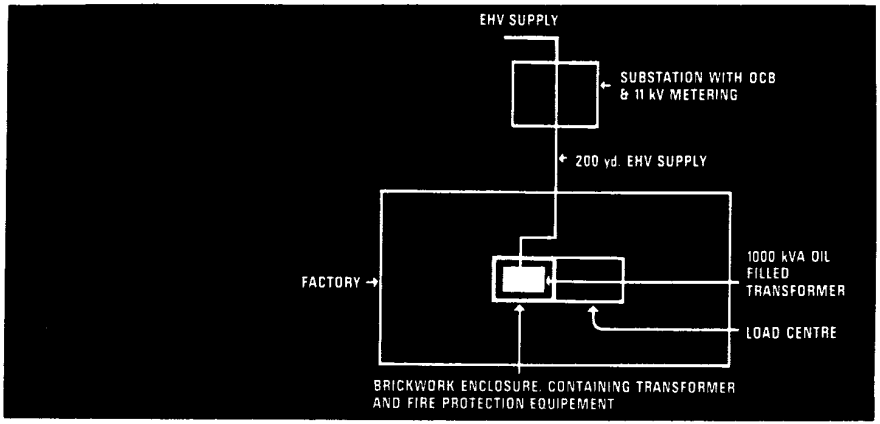

System Conditions:

Load:	700 kVA at 11 KV
Current:	37A
Size of Cable:	3-core 0.015 sq. in (Al)
Resistance of Cable at 20°C:	0.282 ohms/1,000 yds

Capital Costs:

	£
Building to house transformer	500
1000 kVA oil-filled transformer	1,100
Fire protection in substation	300
200 yds. 3C. .15 sq. in Al. cable supplied delivered, installed (including cost of conduits) and terminated	750
	2,650
On cost 8%	210
Total:	**£2,860**

Cost of Operating Losses:

I^2R per cable $= 37^2 \times 0.282 \times \frac{200}{1000} \times 3\text{kW} = 0.22\text{kW}$

Annual unit Losses: $0.22 \times 8760 \times 0.191 \times \frac{.7688}{240}$ £1.2

Demand Losses: $0.22 \times 7.11 =$ £1.6

Total Annual Losses: £2.8

Loss over 25 years at $7\frac{1}{2}\%$ interest (2.8×11.147) = **£31**

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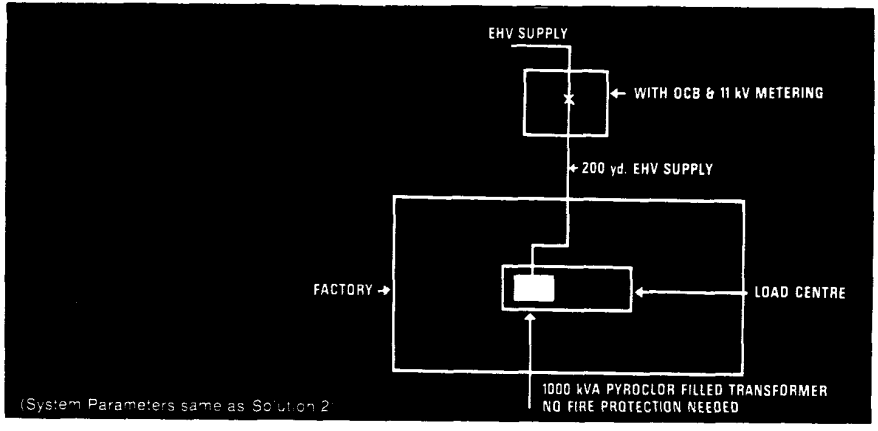

Capital Cost:

	£
Proportion of cost of Load Centre Housing for Transformer	200
1,000 kVA Pyroclor-filled Transformer	1,450
200 yds. 3C. .15 sq. in Al. cable supplied delivered installed (including cost of conduits) and terminated	750
	2,400
On cost 8%	192
Total:	**£2,592**

Cost of Operating Losses:

The cost of operating losses for this solution will be identical to that of Solution B.
Annual Losses: £2.8. Loss over 25 years at 7½% interest: **£31**

Comparison of Costs	Solution A (MV)	Solution B Oil Filled Transformer	Solution C Pyroclor Filled Transformer
Capital Cost, £	4,210	2,860	2,592
Cost of Operating Losses, £	2,478	31	31
Total (£)	6,688	2,891	2,623

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EXAMPLE III

Multi-Storey Buildings Supply to 32 Storey Blocks of Flats.

Details of Load:

No. of consumers	248
ADMD per consumer	8 kW
Total load of building	1984 kW
Load Factor	0.32

Two alternative schemes of supplying this load are considered:

1. One 4 MVA capacity substation on ground floor.

2. One 2 MVA capacity substation on ground floor and one 2 MVA capacity substation on 16th floor.

Cost of Copper Losses:

Based upon latest C.E.G.B. bulk tariff.
Day rate units
(adjusted for 100/- per ton of coal) 0.6873d./unit
Night rate units
(adjusted for 100/- per ton of coal) 0.5573d./unit
Peak Units
(adjusted for 100/- per ton of coal) 1.0873d./unit
82% of losses occur between 07.00 hrs and 23.00 hrs.
9% „ „ „ „ 23.00 hrs. and 07.00 hrs.
9% „ „ „ during peak periods.
Therefore cost per unit
$(0.6873 \times 0.82 \times 0.5573 \times 0.09 + 1.0873 \times 0.09)$d./unit
Plus 5% to cover losses in the system.
$(0.6873 \times 0.82 + 0.5573 \times 0.09 + 1.0873 \times 0.09)\ 1.05$
$= 0.7463$d./unit.
Demand Costs, including 8% to cover losses in the System £7.11/kW

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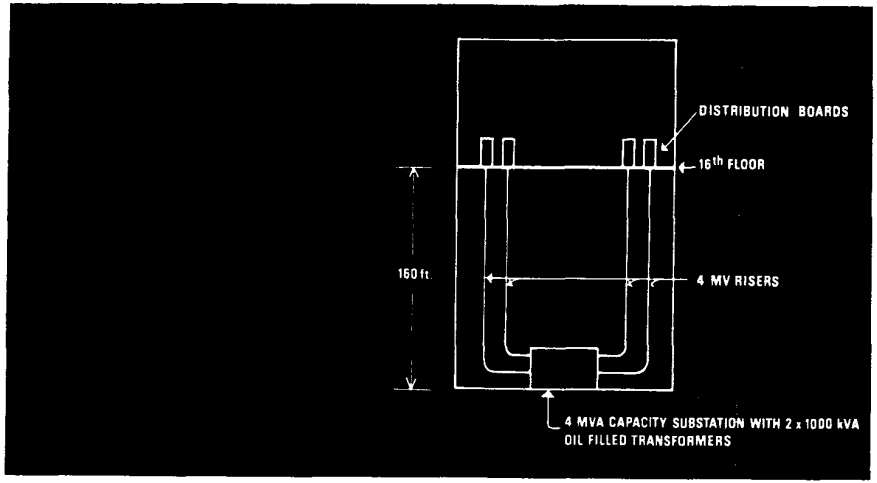

Load Loss Factor:

Loss Load Factor $= 0.3F + 0.7F^2$ where F
$=$ load factor (0.32)
$= 0.168$

Capital Cost:

	£
Contribution to Corporation for Substation Chamber	1200
2 × 1000 kVA oil-filled Transformers at £1100 each	2200
MV Cables between substation and distribution board on 16th floor (53 yds/cable)	300
	3700
On cost 8%	296
	£3996

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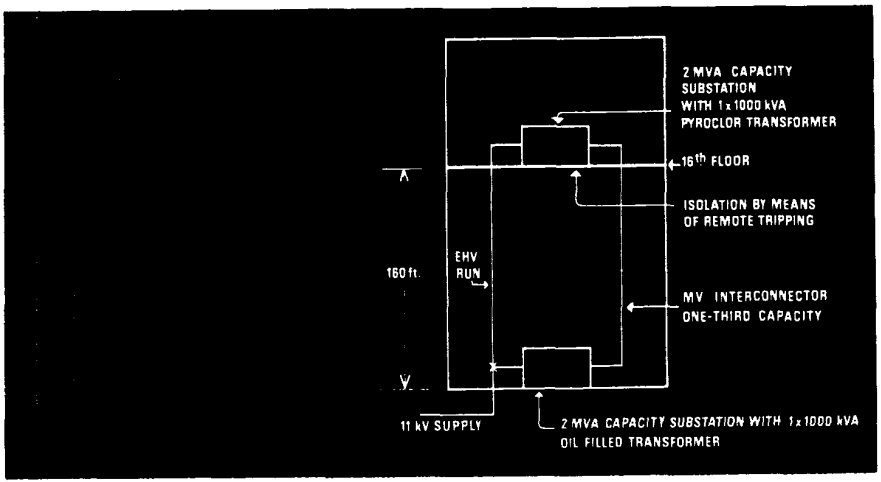

Assumption:

Lift for hoisting equipment to 16th floor available.
Contribution to Corporation £976 per substation.
Transformer in ground floor substation oil-filled
Transformer in 16th floor substation Pyroclor-filled
HV switchgear installed in ground floor substation—isolation of Pyroclor-filled transformer by means of remote tripping.

Cost of Losses:

Assumed temperature of cable 50°C
Resistance of 4C .15 Al. cable at 50°C
= 0.316 ohms/1000 yds.

Current/Conductor/Cable = 345 A
Distance of feed 53 yds. = 0.0168 ohms.
I^2R per cable = $345^2 \times 0.0168 \times 3 \times 10^{-3}$ kw
= 6.00 kW per cable
Annual unit losses in one cable

$$6.00 \times 8760 \times 0.168 \times \frac{0.7463}{240}$$

£27.5
Demand losses per cable
7.11×6.00
£42.7
Total Annual losses per cable
£70.2
Total Annual losses for 4 cables
£280.8

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Annual maintenance cost of 2-1000 kVA oil filled transformers = £2

Present value of above charges over 25 years at interest of 7½%

$$(280.8 + 2) \times 11.147$$

£3140

Capital Costs:

	£
Contribution to Corporation for Substations at £976 each	1953
1 × 1000 kVA oil filled Transformer at £1100	1100
1 × 1000 kVA Pyroclor-filled Transformer at £1450	1450
53 yds. 3C .15 sq. ins. (Al.) cable supplied, delivered, installed and terminated	124
53 yds. 4C 0.3 sq. in. (Al.) cable as above (30% Interconnection between substations)	150
Fencing off transformer, interlocking compound with 11 kV OCB and remote tripping	200
	4976
On Cost 8%	398
	£5374

Cost of Losses:

Resistance of 3C 0.15 Al. cable 0.172 ohms/1000 yds.

Current/Conductor/Cable 50A at 11 kV

Distance of feed 53 yds. = 0.0092 ohms.

I^2R per cable $50^2 \times 0.0092 \times 3 \times 10^{-3}$ kW

0.068 kW

Annual unit losses

$$0.068 \times 8760 \times 0.168 \times \frac{0.7463}{240}$$

£0.3

Demand Losses

$$0.068 \times 7.11$$

£0.48

Total Losses £0.78

Annual maintenance cost of 1000 kVA oil filled transformer £1.

Annual maintenance cost of 1000 kVA Pyroclor-filled transformer NIL

Present value of above charges over 25 years at interest of 7½%

$$(0.78 + 1.0) \times 11.147$$

£20

Summary of Costs

	Solution A 4 MVA S.S. on Ground Floor	Solution B 2 × 2 MVA S.S.
Capital Cost	3996	5374
P.V. of Running Costs	3140	20
Total	7136	5394

Solution B is 24.5% cheaper than Solution A.

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5
Typical properties of Pyroclor

There are two grades of Pyroclor available:

PYROCLOR 5	the recommended fluid for all Pyroclor-filled transformers operating at normal ambient temperature conditions.
PYROCLOR 1	for cases where transformers are required to operate at unusually low temperatures.

Pyroclor 1 and Pyroclor 5 have similar properties but Pyroclor 5 has the additional advantages of lower density and higher relative permittivity.

The following table shows typical values for several properties of Pyroclor 5 and Pyroclor 1.

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Typical Properties of Pyroclor 1 and Pyroclor 5

Property	Test Method	Unit	Pyroclor 1	Pyroclor 5
Appearance	ASTM D1702	—	Clear liquid free from suspended matter and sediment	
Colour	ASTM D1702	APHA	150 max.	150 max.
Density at 20°C	ASTM D1810 and ISO/R 649	g/cm³	1.555 to 1.565	1.502 to 1.524
Refractive Index at 20°C	ASTM D1807	—	1.6160 to 1.6180	1.6173 to 1.6193
Kinematic Viscosity at 20°C	ASTM D445	cSt	24 max.	32 max.
Fire Point	ASTM D92	°C	None to BP	None to BP
Pour Point	ASTM D97	°C	−33 max.	−30 max.
Neutralisation Number	Monsanto	mg KOH/g	0.01 max.	0.01 max.
Inorganic Chlorides	ASTM D1821	ppm Cl	0.1 max.	0.1 max.
Scavenger Content (PPO)	Monsanto	%	ca. 0.2	ca. 0.2
Water Content	ISO/R760	ppm	30 max.	30 max.
Electric Strength at 25°C, 50 Hz	IEC 156	kV	45 min.	45 min.
Resistivity at 100°C, 500V, after 1 minute	Monsanto	T Ω cm	1 min.	1 min.
Dissipation Factor (tan δ) at 100°C, 50 Hz	Monsanto	%	5 max.	5 max.
Relative Permittivity at 100°C, 50 Hz	Monsanto	—	3.8 to 4.0	4.2 to 4.5

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Viscosity

Table 1 shows that the viscosity temperature characteristics of Pyroclor 5 closely resemble mineral oil. Pyroclor 1 is suitable for very low temperature operation.

TABLE 1

Temperature (°C)	Kinematic viscosity (cSt)		
	Pyroclor 1	Pyroclor 5	Typical mineral oil
−30	ca. 16 000	ca. 60 000	2 500
−20	1 800	4 524	750
−10	350	655	270
0	100	162	118
+10	42	57	62
20	21	26	33
30	12.3	15	21
40	7.8	9.4	14
50	5.4	6.4	9.7
60	3.9	4.6	7.2
70	3.0	3.4	5.5
80	2.4	2.7	4.3
90	1.98	2.2	3.4
100	1.70	1.86	2.8

Density

Table 2 shows that Pyroclor has approximately twice the density of mineral oil (15.2 lb. U.K. gallon for Pyroclor 5).

TABLE 2

Temperature (°C)	Density (kg/m³)	
	Pyroclor 1	Pyroclor 5
0	1.578	1.541
10	1.567	1.530
20	1.560	1.520
30	1.545	1.510
40	1.534	1.499
50	1.533	1.488
60	1.512	1.478
70	1.501	1.468
80	1.490	1.457
90	1.479	1.446
100	1.468	1.436

Therefore the Pyroclor-filled transformer is heavier and this raises certain questions regarding the location of Pyroclor transformers, particularly in high-rise buildings. The subject is fully discussed in the section "Pyroclor-filled" transformers in operation" . . . page 66.

Solubility of Water

Water is slightly more soluble in clean Pyroclor than in mineral oil, but there is very little change in the solubility between new and used Pyroclor.

Vapour Pressure

The variation of the vapour pressure of Pyroclor with temperature is shown in Table 3.

TABLE 3

Temperature (°C)	Vapour Pressure (torr)	
	Pyroclor 1	Pyroclor 5
40	<1	<1
60	2	1
80	5	4
100	12	9
120	27	20
140	55	41
160	105	79
180	188	141
200	322	242
220	527	397

In the above table the values at the lower temperatures have been obtained by extrapolation. This procedure was adopted to overcome inherent difficulties in the measurements of low vapour pressures of mixtures of liquids.

Water Absorption

Figure 4 shows the absorption of water from humid air by transformer askarel and mineral oil.

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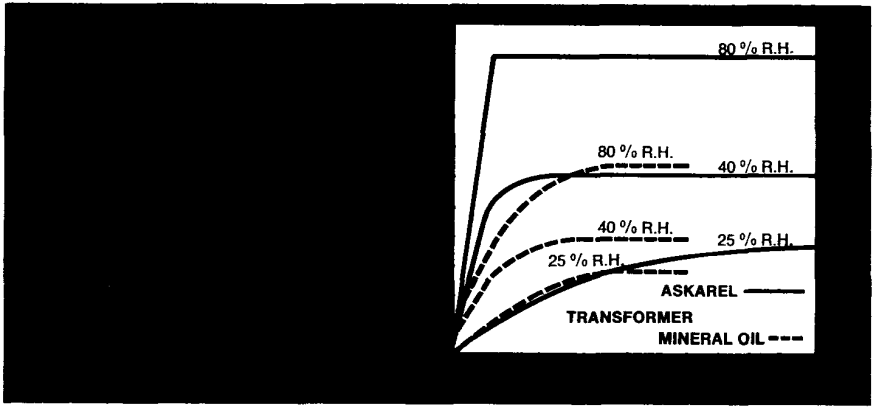

Gas Absorption

The solubility of carbon dioxide, air, nitrogen, and hydrogen chloride is shown in this table.

SOLUBILITY OF GAS IN PYROCLOR

	Percent Gas by Volume Corrected to: 25°C—750mm		0°C—760mm	
	25°C	100°C	25°C	100°C
Carbon dioxide	71	47	—	—
Air	5.7	4.9	5.8	5.0
Nitrogen	6.0	4.8	5.5	4.4
Hydrogen Chloride*	37.8	50.9	—	—

*In the absence of gas scavenger

Stability (Corrosion) Test

Description

A sample of the Pyroclor is heated in darkness for 6 hours at a temperature of 210°C with a prepared piece of aluminium foil. At the end of this period, the appearance, colour, inorganic chlorides and neutralization number of the sample of Pyroclor are determined. The piece of aluminium foil is examined for changes in appearance and its weight loss is determined.

Results:

The values in the following table must not be exceeded for the sample of Pyroclor to pass this test.

Property	Test method	Value
Aluminium foil		
Weight loss (g)	—	0.0
Change in appearance	Visual	None
Pyroclor sample		
Colour (APHA)	ASTM D1702	200 (max)
Inorganic chlorides (ppm)	ASTM D1821	5.0 (max)
Neutralization number (mg KOH/g)	Monsanto	0.01 (max)

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Chemical Properties

Fire Resistance

Although Pyroclor can be shown to have a flash point when examined by the usual laboratory tests, no fire is carried back to the liquid phase, therefore there is no corresponding fire point. The autogenous ignition temperature of Pyroclor can be measured by dropping small quantities of the liquid on the floor of a ceramic lined muffle furnace. The liquid does not take fire until the surface glows with a dull red heat, approximately 700°C. However, once the liquid leaves the hot surface it ceases to burn and does not convey fire by means of a moving stream of liquid. The laboratory of the National Board of Underwriters (U.S.A.) have carried out stringent tests on the fire resistance of this type of liquid and have concluded that it is essentially non-flammable.

Thermal Stability

Pyroclor undergoes no thermal decomposition whatsoever at temperatures below 175°C. If Pyroclor is heated above this temperature by local over-heating or transient arcing, small quantities of hydrogen chloride gas are produced. The gas scavenger additive in Pyroclor absorbs this hydrogen chloride and prevents attack on the iron core or the cellulosic insulation.

If a major internal fault occurs in a Pyroclor-filled transformer which results in a sustained arc below the Pyroclor surface, the extremely high temperature of the arc will decompose the Pyroclor. Major faults are discussed in the section "Pyroclor-filled transformers in operation" . . . page 66.

Resistance to Oxidation

Pyroclor has exceptional resistance to attack by oxygen. When subjected to a bomb test at 140°C in oxygen at a pressure of 250 psig. (17 kg/cm²) there is no evidence of oxidation as judged by development of acidity or the formation of sludge. Hot mineral oil in the presence of oxygen undergoes a series of complex chemical reactions, producing by stages, peroxides, acids, water and other condensation products which eventually form a sludge.

Stability to Hydrolysis

Whilst Pyroclor is resistant to attack by water, water will dissolve in Pyroclor and will deteriorate the electrical properties. Pyroclor has been tested by refluxing with water whilst oxygen was passed through the mixture. No free chlorides were generated during this test. In another test Pyroclor was sealed in a glass capsule with water and heated for six hours at 150°C, and again no chloride formation was detected.

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Dielectric Properties

Although a transformer liquid is principally a coolant, it must also act as an insulation in and between the windings of the transformer. Good dielectric properties are therefore an important characteristic of the fluid.

Dielectric Strength

The dielectric strength of Pyroclor is equal to or better than the best quality mineral oil and has the dielectric qualities required for the voltage stresses encountered in transformers over the entire temperature range of operation.

Permittivity

The permittivity of Pyroclor is much closer to the permittivity of cellulose and this leads to a greater uniformity of stress in impregnated press board.

Loss Tangent

Satisfactory Pyroclor in a transformer may be expected to have considerably higher loss tangent than new material, in the range 0.2 to 0.8 at 100°C.

D.C. Resistivity

Satisfactory Pyroclor sampled from a transformer may have a d.c. resistivity as low as $2.5 \times 10^{10}\Omega$cm at 100°C.

D.C. resistivity of Pyroclor is thus seen to be much lower than that of mineral oil by comparison. This inevitably leads to lower insulation resistance on finished transformers filled with Pyroclor than on their counterparts filled with oil. This is, however, quite normal and is an accepted characteristic of Pyroclor-filled transformers.

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6
Pyroclor-filled Transformers in operation

Effect of Temperature

The electrical engineer can place a Pyroclor-filled transformer anywhere in the distribution system, right at the centre of load if necessary because of these two important factors:

1. Pyroclor is fire-resistant. Where oil will ignite readily, Pyroclor will extinguish flame.

2. Pyroclor, unlike oil, is thermally stable. It suffers no change up to temperatures of 175°C and is affected very little beyond that point.

Let us examine fire resistance more closely and take into account other operating conditions—electrical load (pressure build-up), the effect of time and exterior contamination.

Fire resistance

The fire resistance of Pyroclor may be easily demonstrated. For example if Pyroclor is aerosoled in a container it may be sprayed out onto a conventional gas burner easily extinguishing the flame. A similar test with mineral oil will result in the immediate formation of a powerful jet of burning atomised liquid.

In the laboratory, tests may be conducted using oxyacetylene welding flame and electrically heated metal strips. Pyroclor fluids will not ignite when sprayed on such high temperature sources. In contrast, mineral oil will readily ignite to produce immediate and sustained burning. See also Pyroclor—Flash Point and autogenous ignition . . . page 64.

It is for these reasons that a Pyroclor-filled transformer installation does not require fire fighting equipment, fire walls or any other special fire precautions.

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Should the fluid escape as a result of a severe local fire it would tend to dampen and blanket the flames.

Transient arcing and Pressure build-up

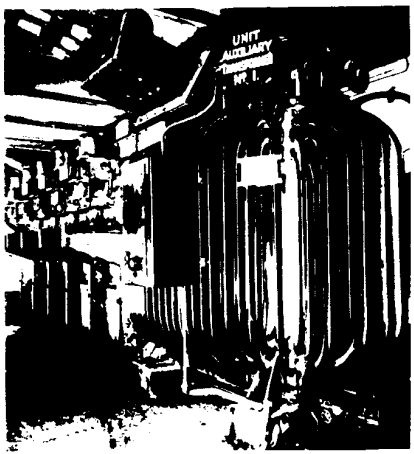
Transient arcing or corona discharge is not unusual in all types of transformers and is usually caused by load fluctuation, switching surges or lightning. If Pyroclor is raised above 175°C by local over-heating or transient arcing small quantities of hydrogen chloride gas may be formed. This gas will be immediately absorbed by the gas scavenger in Pyroclor. Thus any pressure build-up or possible attack on the iron core or cellulosic insulation of the transformer is avoided.

Experience based in over forty years of continuous operation of Pyroclor-filled units shows that the gas scavenger does not normally need replenishment, the initial amount being capable of lasting the life of the transformer.

Sealed Pyroclor-filled transformers are constructed to withstand normal operating pressure fluctuations. Pressure relief valves or bursting discs can be incorporated as additional protection if required.

The effect of time

The breakdown strength of Pyroclor in a properly sealed transformer does not deteriorate with age despite possible variations in power factor and volume resistivity. It is frequently found that megger readings taken on Pyroclor-filled transformers are considerably lower than those taken on oil-filled transformers. This is quite normal and the transformer is quite safe for use. The lower reading is simply a reflection of the much lower DC resistivity of Pyroclor compared with mineral oil. The reliability of Pyroclor is not affected by such low megger readings.



One of the oldest Pyroclor-filled transformers in Britain installed in 1941

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External Contamination

Pyroclor-filled transformers can be operated successfully in adverse environments. Satisfactory operation has been achieved in countless applications which include exposure to the dust and dirt of building sites, the metallic dust of load centred industrial factory installations or even the atmosphere surrounding a blast furnace. The layers of dust which may accumulate on a transformer during the years should have no effect on its operating efficiency.

One source of external contamination which really will affect a Pyroclor-filled transformer in service is water. Water ingress should always be avoided. For example if the Pyroclor reaches a moisture level of 70 ppm the dielectric properties may be seriously degraded. This is one of the main reasons why sealed Pyroclor-filled transformers are recommended. Unsealed units require the installation of protective devices such as silica gel to prevent water being drawn in by the natural breathing of the unit. Experience shows that inadequate maintenance of the breather gel can often render such protection useless.

The Weight of Pyroclor-filled Transformers

Pyroclor is approximately twice as heavy as mineral oil (See table). Generally the weight of a Pyroclor-filled transformer does not pose any particular problem when installed in high rise structures. Local floor strengthening may be necessary but present day architects generally allow for varying load stresses on intermediate floors, the tolerance being well above the weight of a Pyroclor-filled transformer. Often the transformer and control gear can be located near main support areas where additional high floor loading may be tolerated. Pyroclor-filled tranformers have been installed in elevated locations in many tall buildings and rarely has local floor strengthening been required. See page 30.

TABLE

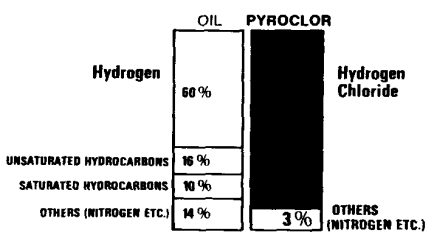
Size (kVA)	Oil-Filled (weights in pounds)	Dry-Type Class C (weights in pounds)	Pyroclor-filled (weights in pounds)
500	5200	5,000	7,000
750	6,600	5,000	8,500
1,000	8,100	7,300	11,000
1,500	14,000	9,800	17,000

Transformer Faults. . Leakage

A properly sealed Pyroclor-filled transformer should normally never leak, but if leakage does occur, Pyroclor should not be fed into a normal drainage system. Monsanto will advise on disposal.

Major Faults

As with most liquid filled transformer units major faults are extremely rare with Pyroclor-filled transformers. However, should sustained arcing result from a major fault condition in a Pyroclor-filled transformer, hydrogen chloride gas would be formed but since hydrogen chloride is a non-combustible/non-explosive gas there will be no danger of a resultant fire. The quantity of gas formed is directly proportional to the intensity of arc and roughly the same amounts of gas are evolved from Pyroclor as from mineral



Decomposition products: Oil and Pyroclor

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oil for a given arc intensity. However, in the case of mineral oil the gases will be a mixture of hydrogen and hydrocarbons. Unlike hydrogen chloride, these gases are flammable over a wide range of gas/air mixtures.

Whereas with transient arcing the gas scavenger additive in Pyroclor-filled transformers adequately copes with gas formation, under major fault conditions this additive would be unable to cope with the quantities of hydrogen chloride formed and the pressure in the transformer would build up. Pyroclor-filled transformers may be fitted with a pressure relief actuator or a pressure bursting disc to give additional protection against such a situation. Therefore, should hydrogen chloride gas be released from the transformer unit as a result of a major fault it would be expected to disperse rapidly as transformers are generally located in well ventilated areas to facilitate cooling. It should be noted that the formation of gas will only continue whilst the arc is actually striking across the fluid. As soon as the overload current protection devices trip, arcing and the formation of hydrogen chloride will cease. Hydrogen chloride is an irritant gas, but it is easily detectable at concentrations below the harmful level. The quantity of hydrogen chloride liberated under major fault conditions is not likely to have a harmful effect on personnel provided they withdraw from the area or wear breathing apparatus. The gas may cause irritation of the eyes, nose, throat and lungs. If necessary irritation of the eyes may be relieved by flushing with water.

Pyroclor derives its fire resistance from the halogen atoms in its molecular structure. Because of this some engineers have supposed that either chlorine or phosgene could be liberated by arcing. Five independent studies in three countries where askarels are extensively used have shown that both theoretically and in practice these gases are NOT produced:

U.S.A.	Underwriters Laboratory Report Underwriters Laboratory Misc. Hazard Report
FRANCE	Jay P "Study of the Formation of Phosgene by Decomposition of Chlorinated Hydrocarbon in the electric arc" Paper: "Chimie et Industrie" 92, No 5 (Nov. 1964)
GERMANY	Chemische Technische Reichsanstalt May 21 1940 Report Farben Fabriken Bayer 1964

Regulations and Codes of Practice For Indoor Transformer Installations

When siting of transformers indoors by the system of load centring building regulations and codes of practice have to be taken into account.

The "regulations For the Electrical Equipment of Buildings" published by the Institution of Electrical Engineers, 1966 edition, Section C-5 (Page 63) recommends:

"Where fixed oil-filled apparatus of a capacity exceeding 20 gallons is used, means shall be provided for draining away surplus oil and for preventing the escape of oil into any other part of the building."

Note: It is recommended that oil-filled apparatus installed within a building and having an oil capacity exceeding 50 gallons be placed in a chamber of fire-resisting construction, ventilated to the outside of the building only.

There is no British Code of Practice covering the installation of Pyroclor-filled transformers. Reference can be made to the National Electric Code of the American Standards Association (1956) Article 450, Section 4522, page 152.

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7 Fluid Checks

1. Sealed Transformers

A properly designed, sealed Pyroclor-filled transformer needs *no maintenance*.

2. Unsealed Transformers

Unsealed transformers (e.g. breather types) have been manufactured. Even these, when Pyroclor-filled, require no maintenance in the true sense. However, inspection of the fluid may be necessary at intervals to determine whether it has retained in full original electrical properties. Either the transformer manufacturer or user may wish to perform these simple fluid checks and the following is the procedure.

Sampling Procedure

A sample should be taken as close to the top of the liquid surface as possible in addition to a sample from the bottom of the transformer. If sampling tube connections are attached to the valves for ease of sampling, tubes should be made of either clean glass, stainless steel, aluminium or tin for rigid types and silicone rubber or teflon tubing for flexible types. It is best to take the sample from a transformer which is warm and operating at average or maximum load. Sampling of the warm Pyroclor more truly represents its condition during operation.

Samples of Pyroclor to be used in tests of electrical properties, i.e. resistivity and power factor, are very easily contaminated, and it is essential to follow the procedure recommended below in order to obtain true measurements. If a result is poorer than anticipated, the whole procedure should be repeated for a second sample (more than once if necessary).

Sample Bottle

Narrow necked glass bottle with bakelite screw-on cap is suitable. The sealing washer inside the cap should preferably be PTFE, but a paper disc can be used, if covered by a layer of aluminium foil.
Other seals such as rubber, etc., will cause sample contamination.

Preparation of the Sample Bottle

(a) If the bottle is new, wash out the bottle and cap with water and detergent (household type), rinse out with running warm water and then rinse three times with distilled water. If *analytical quality* acetone is available, give a final rinse with this to speed the drying process. (Do not use technical quality acetone as contamination is likely.) Dry in a clean oven for half an hour at approximately 110°C (longer if the acetone rinse is omitted) and keep the bottle closed in a drying cabinet until required.

(b) If the bottle has been previously used (for Pyroclor sampling), first wash out with a hydrocarbon solvent such as benzene or petroleum ether, then carry out the cleaning procedure as described above.

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The Sampling Operation

Remove the cap from the sample point and wipe the end of the pipe with a dry tissue. Place a receptacle under the sample pipe and run off about five litres. Then without stopping the flow place the sample bottle under the pipe and rinse out the internal surfaces (not forgetting the screw cap) three times with Pyroclor before filling with sample to about 90% full. Take special care to avoid touching the sample point with the neck of the sample bottle. Put the screw cap on and tighten immediately. Close sample discharge valve and replace cap. Clean the exterior of the bottle as necessary with a clean tissue. The material used for rinsing etc. should be discarded. (See section 9 regarding arrangements for disposal of waste product.)

If the sample is to be stored for an appreciable time before testing, the bottle (even if of dark glass) should be wrapped in aluminium foil or opaque paper and placed in a cardboard tube or other container suitable for transportation.
Sampling should be preferably carried out under cover, if this is impossible, precautions must be taken to keep any rain from the vicinity of the sample pipe and bottles. Sampling out of doors in wet weather conditions should be avoided, if at all possible. In such circumstances make a note of the adverse conditions.

Routine samples of Pyroclor should be checked for:

1. *Appearance*
2. *Dielectric Strength*
3. *Moisture Content*
4. *Loss Tangent*

1. Appearance

A blue, green or red cast in clear Pyroclor shows that it is extracting colour from internal materials. This is not an operating hazard when the dielectric strength stays above 40 kV, when the moisture content is low and when there is no leakage. However, this condition calls for a check on the interior construction of the transformer and a re-assessment of the compatibility of materials used in its construction. If the Pyroclor is dark brown or black, with small carbon particles present and if the dielectric strength is low, then heavy arcing has been occurring and immediate action should be taken.

Because Pyroclor does not oxidise, sludge or decompose in normal use it can suffer only minor contamination. Turbidity combined with high dielectric strength is due to insulation particles, metallic dust or dirt in the Pyroclor. However, insulation efficiency may still be excellent, even though the D.C. resistivity may be impaired. Care must be taken to distinguish this particle contamination from the precipitation of the gas scavenger which occurs at low temperatures.

2. Dielectric Strength

Measure this following the procedure in BS 148:1959. Appendix F. If the dielectric strength has decreased significantly below 40 kV this indicates moisture pick-up, arcing or both and immediate action should be taken.
Dielectric strength is a major indicator of the operating efficiency of Pyroclor. Visual and dielectric tests are the only ones necessary for routine inspection and well-sealed transformers have run satisfactorily for 30 years on the original Pyroclor.

3. Moisture Content

Water will migrate from a transformer's solid insulation to the Pyroclor liquid and vice versa, depending on temperature. When the transformer is hot, the moisture is likely to be found in the Pyroclor and accounts largely for periodic variations in dielectric strength—higher in winter months. Should the dielectric strength ever drop below 40 kV, measure the water content by the Karl Fischer method in ASTM D 1533-61. Over 70 ppm the dielectric strength of Pyroclor drops below the efficient insulating value and immediate action should be taken.

4. Loss Tangent

The loss tangent (power factor) of a new transformer should range from 1% to no more than 5%. It is normal to expect the loss tangent to increase in a satisfactorily operating

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Pyroclor-filled transformer, but the overall loss tangent will not be much beyond 5%. The moisture level and dielectric strength will remain satisfactory.

Occasionally the loss tangent of an unarced, satisfactorily operating Pyroclor-filled transformer may be relatively high, for example 15%. The loss tangent of the Pyroclor will also be high, as much as 50% at 20°C and 50 Hz. If this is the case, check the dielectric strength. If there is a downward trend, this indicates the probability of moisture entry which should be confirmed by the Karl Fischer test for water content.

Reclamation

Provision is made to reclaim the Pyroclor in the event of unexpected deterioration due to minor arcing, entrance of moisture and the presence of other contaminants. Reclamation services are offered by Dalton & Co. Belper, Derbyshire.

The following table gives the typical properties of new and used Pyroclor.

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Typical Values found in Pyroclor under various conditions

Inspection check points	A New Pyroclor	B Pyroclor in properly built[1] new or rebuilt units prior to use	B After normal operation (a survey of 50 units most 2 to 5 years old, some 10)	D Non-arced but slightly contaminated Pyroclor in improperly built units,[1] new or slightly used	E Same Pyroclor as in Column D—after refining	F Heavily arced Pyroclor due to neglect and internal electrical malfunction
Colour	Light straw	Light straw	Light straw	Can have blue green or red cast	Cast remains showing extraction of soluble colour	Black
Clarity	Clear, free from particles	Clear, practically free from particles	Clear, trace of particles	Clear slight amount of particles	Clear free from particles	Contains carbon particles
Water content	30 ppm	30 ppm	10—70 ppm, all dissolved water	20—100 ppm, all dissolved water	30 ppm max	Near 152 ppm saturation level plus possible undissolved water
Dielectric strength at 25° C— B.S. 148 (kV)	40 kV min	40—55 kV	40—51 kV	34—48 kV	40 kV min	6—17 kV
D.C. restivity at 100° C, 500 v/mm (T Ω cm)	[2]	0.04 minimum usually at least 0.1	0.015 to 0.040	About 0.005	At least 1.5	About 0.003
Loss tangent (power factor) at 50 c/s 1 kV/mm 100° C (%) 25° C (%)	 2 to 5 0.05 to 0.1	 10 to 25 0.5 to 2	 10 to near 80 0.5 to near 10	 30 to near 100 about 7 to over 15	 2 to 5 0.1 to 0.2	 100 at least 255

1. A properly built transformer is defined as one in which the materials of construction are chemically and electrically compatible with Pyroclor.

2. Above data relates to Pyroclor fluid not to the insulation resistance or loss tangent measurements on the transformer itself.

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8
Design of Pyroclor-filled Transformer

Compatibility of Construction Materials:

Pyroclor is an entirely different material from mineral oil despite some superficial physical resemblances. For example, Pyroclor will soften and plasticize a number of plastics and resins that are suitable for use in mineral oil transformers. If such incompatible materials are polar, they will ionize to a greater extent in Pyroclor than they would in mineral oil and so adversely affect the dielectric strength. For these reasons, only materials compatible with Pyroclor should be used in transformer construction.

Pyroclor has a greater tendency to "creep" than oil. It is by its nature a more searching and penetrating liquid. For this reason, Pyroclor should not be added either as re-fill or top up to a mineral oil transformer. Conversely, a Pyroclor-filled transformer should not be topped up with mineral oil. Mineral oil is soluble in Pyroclor but any oil present will reduce its fire resistance. It is recommended that a maximum oil content of 2% is not exceeded and mixing of the two coolants is avoided at all times.

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Coolant Volume

For economy, a Pyroclor-filled transformer design usually attempts to keep the liquid volume required as low as practical because it is more costly than oil. However, even without radical re-design the volume of fluid can be reduced by rounding the corners of the tank. Cooling tubes with oval or star-shaped cross-section will also reduce the fluid volume.

Hermetically Sealed Units

Because of their dependability and long service life, Pyroclor-filled transformers are normally hermetically sealed. A sealed unit made with compatible materials, requires no subsequent maintenance or fluid testing. Sealed units will also afford the most reliable protection against entry of moisture.

Sealed units are sometimes designed with "top hat" construction providing an expansion chamber with air or nitrogen filled space. The gas in this chamber is often sealed in at a slight negative gauge pressure when cold to allow for the expansion of the coolant at operating temperatures. With sealed units, it is customary to install rupture discs for pressure relief. They are constructed to burst at 10, 14, 15 or 18 pounds pressure, plus or minus 3 pounds. They are usually sized such that the transformer tank withstands 25% over normal operating pressure. An alternative pressure relief system is the use of a spring-actuated pressure relief vent.

Tap Changers

Since frequent arcing deteriorates Pyroclor, it is unsuitable for switchgear and on-load tap changers below the liquid surface are not recommended. The normal construction practice is to provide some form of mechanical interlock on tap changing equipment to prevent it being actuated on load.

Terminal Entry

It is recommended that terminal connections be brought through side walls below the surface of the Pyroclor as free water would tend to float on the more dense Pyroclor. If this is not possible then it is recommended that the terminals be encased in a suitable sleeving to prevent the possibility of a flash over in the rare event that water enters the transformer and migrates to the liquid surface.

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9
Storage, Handling and Disposal of Pyroclor

Drums

Inside storage is recommended to prevent contamination of the product by water. If the drums have to be stored outside they should be stacked on their sides to prevent water accumulating around the bungs and being breathed into the drum during severe ambient temperature changes.

Drum storage areas should be organised so that any leakages are collected for safe disposal.
Partially emptied drums should not be left open to the air and filled transformers should be closed to the air as soon as possible.

Bulk

The supply of Pyroclor in bulk tank car loads, offers many advantages to medium and large volume users, compared with drum deliveries. Unloading, storing and transferring to the transformers is safer, easier, faster and cheaper. Material losses due to spillage and incomplete emptying of drums are eliminated. The possibility of product contamination during handling is greatly reduced.

Even where storage and handling facilities are not at present available, the economics of bulk handling may quickly pay for the tanks and piping systems required.

A booklet indicating the type of system necessary for the efficient handling of Pyroclor in bulk is available from Monsanto.

As soon as a changeover to bulk delivery is contemplated, experienced Monsanto personnel will be available for site discussions regarding the most efficient type of installation for the particular location and an offloading procedure appropriate to that particular installation.

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A modern installation for filling transformers with Pyroclor from a bulk storage tank.

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Handling Precautions

Pyroclor drums and containers carry the following label which gives general instructions for handling:

IMPORTANT **CHLORODIPHENYLS (42%-54%) (or 60%) (PCB)**

This product contains POLYCHLORINATED BIPHENYLS (PCB's) which some studies have shown may be persistent, an environmental contaminant and, possibly, injurious to certain forms of bird, aquatic and animal life.
PREVENT ANY ENTRY INTO THE ENVIRONMENT THROUGH SPILLS, LEAKAGE, DISPOSAL, VAPOURISATION, RE-USE OF CONTAINERS OR OTHERWISE.
SPILLS, LEAKAGES AND WASTE PRODUCT MUST BE COLLECTED.
Use of this product must be restricted to applications which can be controlled so that entry into the environment does not occur and to applications in which it cannot come into contact with food, animal feedstuffs or pharmaceuticals.
HARMFUL SUBSTANCE IF TAKEN INTERNALLY OR IF IN PROLONGED CONTACT WITH THE SKIN.
CAUSES IRRITATION OF SKIN AND EYES.
DURING SHIPMENT AVOID SPILLS AND LEAKAGE INTO INLAND WATERWAYS AND THE SEA.
Store away from food, animal feedstuffs and pharmaceuticals.
Keep container tightly closed.
Do not eat or smoke when using.
Avoid breathing vapours, mist or fumes.
Do not wear contaminated clothing.
Wash product from skin with soap and water.
Wash eyes by flushing with water.

In addition to the above we can add that:

1. Animal toxicity tests (small mammals) indicate that acute oral toxicity is low but that acute dermal toxicity may be moderate.

2. When handling the fluid minimise contact with the skin and wash any off with soap and water. People with sensitive skins should wear gloves resistant to chlorinated solvents or apply a silicone hand cream.

3. Should Pyroclor accidentally splash or be rubbed into the eyes, they should be rinsed thoroughly with water for a few minutes. It is suggested that all operators be provided with safety glasses as Pyroclor will cause pain if it gets into the eyes.

4. Elementary rules of hygiene should be applied—such as not smoking, eating or drinking during handling and contaminated clothing should be discarded.

5. Pyroclor should be handled at ambient temperatures in well ventilated areas. If a Pyroclor-filled transformer is to be opened, it should be allowed to cool down to room temperature before opening it. If hot Pyroclor has to be handled, a respirator with an active carbon canister should be worn.

Disposal of empty drums and waste Pyroclor

Empty drums should not be re-used for anything except scrap Pyroclor. Unwanted empty drums should be disposed of by a specialised waste disposal contractor familiar with PCB's who will crush the drums and bury them on an approved toxic dump in accordance with local regulations. Handling of Pyroclor in bulk will minimise the problems associated with handling of drums. Waste Pyroclor should be disposed of by special high temperature incineration at 1000°C minimum with a residence time of 1.5 seconds or longer or alternatively by a method conforming to local regulations.

Care must be exercised during such disposal and the ultimate use of Pyroclor to avoid pollution, particularly of sewers and waterways.

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11 Glossary of Terms

The following glossary of terms has been designed as an alphabetical ready-reference guide.

Applications

Pyroclor-filled transformers have a wide range of applications including steel works, glass factories, public buildings, stores and offices. See pages 5-70.
"Uses of Pyroclor-filled Transformers".

Arcing

Arcing will occur beneath the surface of Pyroclor analogous to arcing mineral oil in the event of a major electrical breakdown. However, the only gaseous product of the decomposition of Pyroclor by electric arc is hydrogen chloride which is non-explosive and non-flammable. This compares with the production of hydrogen by arcing under the surface of mineral oil. However, whereas the hydrogen produced with mineral oil tends to cool the arc, the hydrogen chloride produced with Pyroclor does not have this effect and arcing would tend to persist rather longer with Pyroclor than with mineral oil. In the event of small transient arcs taking place, the small quantities of hydrogen chloride which would affect the electrical properties of Pyroclor are absorbed by a gas scavenger which is dissolved in the liquid, but this gas scavenger is not designed to cope with the large quantities of gas produced in the event of a major internal fault.

Askarel

An askarel is defined as a liquid which is itself fire resistant and does not produce under arc conditions or thermal decomposition mixtures of gases which are themselves explosive or flammable.
Askerel is a generic term for a group of fire resistant products used as electrical insulating media.

Breathers

Where breather transformers are filled with Pyroclor the silica gel breather must be regularly maintained to prevent it becoming water saturated and allowing entry of moisture into the transformer. The fluid in such units should be regularly inspected. (*See* External Contamination *page* 68.)

Conservator

If a breather unit is used it would be normal also to use a conservator to prevent loss of the volatile component of the Pyroclor through the breather.

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Class A

Pyroclor was developed for this class of insulation.

Compatibility of Materials

Pyroclor is a natural plasticiser for a variety of resins and plastics normally used in oil-filled transformers. If polar, these materials ionise to a greater extent in Pyroclor and so increase dielectric losses.

Cost

Although Pyroclor itself is more expensive than mineral oil and the basic cost of a Pyroclor-filled transformer is still about 30% greater than that of its oil-filled counterpart, the installed cost can be significantly less as a result of economies which can be made in installation. No fire-fighting equipment, fire walls, pebble drains, etc., are required. Siting Pyroclor-filled transformers near the load centre reduces L.V. cable runs and maintenance bills are almost entirely eliminated (*see pages 48 to 56 for further details on economies*).

D.C. Resistivity

D.C. Resistivity of Pyroclor is lower than that of mineral oil. Thus a low resistivity reading on a Pyroclor transformer, for example 10 megohms, is quite normal and does not indicate deterioration of the fluid. Such a transformer would be entirely safe for service. A reading of 100 megohms would be expected with an oil-filled transformer.

Dielectric Strength

The dielectric strength of Pyroclor is equal to, if not better than, best quality mineral oils and is suitable for the entire temperature range of transformer operation.

Explosion Risk

In the unlikely event of a persistent arc beneath the surface of Pyroclor owing to a major insulation breakdown the tank could be split by the pressure increase due to generation of gases. Pressure relief valves or bursting discs are usually incorporated to safeguard against this possibility. In an oil-filled transformer there is the added possibility of explosion due to ignition of hydrogen evolved during arcing. Only non-explosive gases are evolved when Pyroclor is arced.

Filling

Pyroclor in drums or in bulk is ready for filling transformers directly. Filling of Pyroclor transformers is best carried out indoors on a dry day and care should be taken to seal the transformers as quickly as possible afterwards to prevent ingress of moisture.

Fire Resistance

Askarels are the most widely used fire-resistant transformer coolant and installations can safely be made in areas where fire risk is considerable, especially indoors.

Gases

Phosgene and chlorine are NOT formed as decomposition products of Pyroclor. The main decomposition product is hydrogen chloride.

Handling Precautions

See page 77.

Heat Transfer

The heat transfer characteristics of Pyroclor are similar to those of mineral oil.

Hydrolysis

Pyroclor is resistant to attack by water; although water will dissolve in Pyroclor and naturally affect its dielectric properties. At room temperature the maximum solubility of water in Pyroclor is about 100 parts per million and Pyroclor normally contains less than 30 parts per million.

Insurance

In some countries fire insurance premiums can be reduced with Pyroclor-filled transformer installations.

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Installation

There is no British Code of Practice covering the installation of askarel-filled transformers. Reference, however, may be made to the Canadian Code of Practice and the National Electric Code of the American Standards Association (1956) Article 450, Section 4522, page 156.

L.V. Cable Runs

Pyroclor-filled transformers can be installed at the load centre and long runs of expensive low-voltage cable are reduced. *See* "Cost Savings using Pyroclor-filled Transformers", pages 48-56.

Load Centring

Details of cable economies due to load centring Pyroclor-filled transformers are shown on pages 48-56.

Maintenance

A properly designed, sealed Pyroclor-filled transformer needs no maintenance. Unsealed transformers require inspection. *See page* 70.

Megger Readings

It is frequently found that megger readings taken on Pyroclor-filled transformers are much lower than those on their oil-filled counterparts. This is a reflection of the very much lower d.c. resistivity of Pyroclor compared with mineral oil.

Noise

Pyroclor-filled transformers are quiet in operation because of the effective dampening of core noise by the high density coolant.

Over-Voltage

Pyroclor-filled transformers can be installed where over-voltages due to lightning or switching surges may occur.

Oxidation

Pyroclor has exceptional resistance to oxidation. If an askarel-filled transformer is operated under normal conditions the fluid need not be changed or filtered during the life of the transformer, page 64.

Permittivity

Compared with the permittivity of mineral oil that of Pyroclor is much closer to the value for cellulose, leading to greater uniformity of stress in impregnated press board and paper windings.

Reliability

Properly designed and installed, askarel-filled transformers will give trouble-free service for a minimum of 30 years. Since their introduction in 1932 the manufacturers report finding the overall failure rate to be less than 0.5% for all units under test and service conditions.

Refilling Oil Units

The replacement of existing oil filling in transformers is not generally recommended since Pyroclor may attack the gaskets and many of the sleeving materials, paints and varnishes commonly used with oil. Accordingly, leakage may occur or electrical breakdown may result. In theory, if all materials could be replaced with Pyroclor resistant materials, then the oil could be replaced by Pyroclor.

Sealed Transformers

Properly designed, sealed transformers need no maintenance. These are usually hermetically sealed with an air or nitrogen space to allow for expansion.

Siting

Examples of economies achieved by siting Pyroclor-filled transformers indoors, close to the load centre, are given on pages 48-56 and are available separately in detail from Monsanto.

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Size

Pyroclor-filled transformers are usually a little smaller and more compact than other units and can operate at higher voltages than air-cooled transformers.

Solubility

Water is slightly more soluble in clean Pyroclor than in mineral oil, but solubility in used or unused Pyroclor is much the same (solubility approximately 130 p.p.m. at 30°C. as opposed to approximately 90 p.p.m. at 30°C. in new mineral oil).

Space Saving

Well-sealed transformers can be used in dusty or corrosive atmospheres in such spaces unsuitable for other equipment *e.g.* Pyroclor-filled transformers have been installed close by a battery of blast furnaces.

Switchgear

Pyroclor is unsuitable for use in switchgear since arcing produces hydrogen chloride gas which in moist atmospheres might cause attack of the metallic parts of the switchgear.

Tap Changing

On load tap changing beneath the surface of the Pyroclor will result in the formation of hydrogen chloride gas and carbon. It is therefore not recommended.

Thermal Stability

Pyroclor is thermally stable up to 175°C. Small quantities of hydrogen chloride are produced above this temperature but are absorbed by the gas scavenger, preventing attack on the iron core or cellulosic insulation.

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Toxicity

Animal toxicity tests indicate that acute oral toxicity is low but that acute dermal toxicity may be moderate. See page 77.

Vapour Pressure

The variation of vapour pressure of Pyroclor and Pyroclor ETR with temperature is shown on page 62.

Viscosity

Pyroclor has been blended to match the viscosity-temperature characteristics of mineral oil (*see page* 62).

Voltages

Askarel transformers working at 120 kV have been made, but most work in the region of 11 kV since this is the usual level of distribution voltage. The majority of units, normally working indoors, are found in the range between 50 kVA and 4 MVA.

Volume Reduction

For successful transformer design using Pyroclor it is desirable to keep the liquid volume to a minimum to save cost. Useful economies can be made with round corner tanks, oval or star-shaped cooling tubes. Dead space fillings such as low resin wood or even glass marbles have also been used.

Venting

If Pyroclor-filled transformers are installed in confined spaces it is normal to vent the transformer to atmosphere. The vents are closed by rupture discs. Although there is no Code of Practice in the U.K. for the installation of Pyroclor-filled transformers, this recommendation is in line with the Canadian Code of Practice covering the installation of such transformers. The National Electrical Code of the American Standards Association (1956), Article 450, Section 4522, page 156, also deals with the installation of askarel-filled transformers.

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