DIELECTRIC LIQUID

PYRALENE

PYRALENE

REFERENCE PAMPHLET P-10

JANUARY. 1962

GENERAL OBSERVATIONS ON THE "PYRALENE" LIQUID DIELECTRICS

(Trade-Mark)

This pamphlet is destined for engineers and manufacturers who wish to have a quick comprehensive review of the properties and main applications of Pyralene.

For any well known application refer to the special pamphlet.

For any application not mentioned in our pamphlet, it will be advisable to consult our Technical Department which in collaboration with our laboratories is at the disposal of all persons interested in Pyralene.

I — GENERAL

I.1 — ORIGIN OF PYRALENE

Since 1934, French manufacturing companies have been studying the production and use of synthetic dielectrics. This research made it possible in 1941 to meet a shortage of mineral oil, and over one thousand five hundred transformers were immersed in these synthetic dielectrics.

These dielectrics, known under the names : Dielectrol, Chloranol, Afcoline, were substitute products, and in 1946 they were discontinued.

Experience gained with these dielectrics was not wasted for in 1947 it was found possible to manufacture succesfully entirely different chemical products, their physical and electrical characteristics. Comply with the recognised International characteristics which describe "Askarels".

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LABORDE 91-60

I.2 — DIELECTRIC LIQUIDS

I.2.1. — Mineral oil :

Up to the last few years, mineral oil was the liquid dielectric most currently used by the electrical industry.

Mineral oil has good insulating characteristics but it also has a serious draw back, which is the main reason for making its use difficult : mineral oil tends to oxidise, oxidation of the oil gives rapidly rise to :

— sludge formation;

— increase in viscosity, acidity and hygroscopicity;

— decrease of its dielectric strength and insulating resistance.

Furthermore, mineral oil, when subjected to intense electrical fields undergoes a chemical change which is well known as " Wax X " formation.

Moreover, mineral oil being a hydro carbon ignites when decomposed by heat or by an electric arc. The products evolved by decompositions include hydrogen which reacts violently with oxygen of the air, and this reaction is followed by an explosion and fire.

I.2.2. — Non-inflammable dielectric liquid :

To eliminate all danger of fire, a dielectric liquid which is decomposed by heat or by an electric arc must not evolve any free hydrogen, furthermore, gases evolved by decomposition must be stable even at a temperature which is higher than that which caused the decomposition : this is the definition of dielectrics belonging to the " ASKAREL " class.

Hydrogen chloride evolved by combining chlorine and hydrogen is a gas which answers this requirement.

Since an atom of chlorine is necessary to saturate an hydrogen atom, the chlorinated dielectric must contain at least as many chlorine as hydrogen atoms.

I.3 — NATURE OF PYRALENE :

I.3.1. — Formula :

They are essentially chlorinated derivatives of benzene type molecules.

Diphenyl which is the result of the link of two benzene molecules is the basic element in the manufacture of chlorinated dielectrics.

In its formula $C^{12}\ H^{10}$
at least 5 chlorine atoms must be substituted to comply with non inflammability conditions.

PHYSICAL AND CHEMICAL, CHARACTERISTICS OF PYRALENE

(Average values)

REFERENCE	PYRALENE 1499	PYRALENE 1496	PYRALENE 1476	PYRALENE 1482	PYRALENE 1477	PYRALENE 1467	PYRALENE 1470
Appearance	clear, almost colourless liquid	clear, almost colourless liquid	clear, almost colourless liquid	clear, almost colourless liquid	clear, almost colourless liquid	clear, almost colourless liquid	clear, almost colourless liquid
Pour point in °C	— 18	— 9	+ 10	+ 30	— 45	— 32	— 45
Viscosity in cst	8 at 55°C	5.4 at 80°C	6.5 at 100°C	14 at 100°C	2.8 at 55°C	2.5 at 80°C	1.9 at 80°C
Specific gravity at 100 °C	1.31	1.38	1.47	1.44	1.41	1.48	1.46
at 20 °C	1.38	1.46	1.55	1.63	1.49	1.56	1.54
Coefficient of expansion	0.00068	0.000685	0.000689	0.00075	0.00075	0.00073	0.00070
Specific heat in cal/g/°C (20-100°)	0.28	0.27	0.26	0.25	0.27	0.26	0.26
Conductivity heat at 40 °C $\frac{K\ cal}{mh\ °C}$	0.095	0.091	0.087	0.083	0.091	0.083	0.083
Refractive Index at 25° C	1.624	1.630	1.637	1.646	1.604	1.615	1.608
Evaporation losses	0.12 (2hrs at 125°C)	0.07 (2hrs at 125°C)	0.03 (2hrs at 125°C)	0.01 (2hrs at 125°C)	3 (6hrs at 100°C)	2.5 (6hrs at 100°C)	3 6hrs at 150°C)
Flash point	nil	nil	nil	nil	nil	nil	nil
Acidity (mg KOH/g)	0.01 max.	0.01 max.	0.01 max.	0.01 max.	0.01 max.	0.01 max.	0.01 max.
Chlorine ion per cent	10^{-5} max.	10^{-5} max.	10^{-5} max.	10^{-5} max.	10^{-5} max.	5.10^{-4} max.	5.10^{-4} max.
Dielectric constant at 100 °C (50 to 1.000 c/s)	4.8	4.6	4.2	3.8	4.2	4	4
Tangente of the loss angle at 100 °C (50 c/s)	0.04 max.	0.03 max.	0.015 max.	0.01 max.	0.04 max.	0.03 max.	0.03 max.
Resistivity at 100 °C after 1 min. under 200 V/mm. in Ω cm/cm²	1×10^{12} min.	1×10^{12} min.	1×10^{12} min.	1×10^{12} min.	0.6×10^{12} min.	1×10^{12} min.	1×10^{12} min.
Dielectric strength in kV/cm (ASTM)	200 min.	200 min.	200 min.	200 min.	200 min.	200 min.	200 min.
Applications	capacitors	capacitors	capacitors	cables-coplasticisers	capacitors	transformers	transformers

1.3.2. — **Adapting the Pyralene for use :**

— by varying the rate of chlorination of the diphenyl;

— by mixing two or more Pyralenes.

It is possible to obtain quite a range of Pyralene which will comply with the requirements of the electrical industry : viscosity, setting point, loss by evaporation, etc...

Moreover, these products undergo special purification to give them the dielectric characteristics essential for the insulation of electrical apparatus.

In short, the chemical industry has made synthetic dielectric liquids available for the electrical industry.

— non-inflammable, having no explosive vapours;

— stable, i.e. non oxidisable and non ageing;

— perfectly adapted for use

— excellent insulators.

2 — DIFFERENT TYPES OF PYRALENE

There are three distinct types of Pyralene having characteristics which are adapted to the three main applications:

— for transformers: PYRALENE 1467 and 1470;

— for capacitors: PYRALENE 1476, 1498, 1499 and 1477;

— for various applications : (plasticisers) : PYRALENE 1482 and 1476.

3 — GENERAL PROPERTIES OF PYRALENE

The characteristics of Pyralene and their incidence on the design of electrical equipment are reviewed in our pamphlets outlining their applications.

3.1. — PHYSICAL PROPERTIES :

Pyralenes are colourless liquids.

Their specific gravity is higher than that of mineral oils. It varies from 1,38 to, 1,58 at 100°C.

Their viscosity varies from 0,5 to 14 cst. at 100°C.

Their pour point lies between — 50°C and + 30°C.

Their specific heat is characteristic of a good cooling liquid.

Their vapour pressure remains always low, even at temperatures exceeding 120°C.

Their losses by evaporation are negligible.

Their non-inflammability is guaranteed. (Official report on tests made by the Conservatoire des Arts et Métiers).

3.2 — CHEMICAL PROPERTIES :

Pyralene are :

— completely neutral (acidity less than 0,01 mg KOH per gram of Pyralene);

— stable, and without any tendency to form sludge ;

— slightly hygroscopic, they can dissolve a maximum of 100 parts water per million at 20°C. Commercially the water content of Pyralene is less than 30 parts per million,

— have no action on commonly used metals : copper, aluminium, iron, bronze, tin, etc.

Pyralene dissolves a certain number of materials used in the construction of electrical equipment. Compatibility tests have been systematically carried out by our laboratories and by those of the electrical industry, results obtained guarantee the choice of materials : solid insulators, varnishes, resins, lacquers, gaskets, etc.

Under the influence of an electric arc, Pyralene is decomposed into a certain number of gases, mainly hydrochloric acid (98 per cent). **No toxic gases, free chlorine or phosgene are found** by analysis (tests by official laboratories).

3.3 — ELECTRICAL PROPERTIES

3.3.1. — **Dielectric constant and dielectric losses :**

Pyralene, polar liquids, are characterised by :

— **high dielectric constant** (approximately 5 as against 2,5 for mineral oil);

— **low dielectric losses,** slightly higher, owing to their polarity, than with new mineral oil.

3.3.2. — Dielectric strenght :

The dielectric strength of Pyralene is very high, currently, reaching 200 kV/cm measured with an A.S.T.M. spark-gap (space between discs 2,5 mm).

3.3.3. — **Direct current resistivity :**

At 100°C under 500 V with 2,5 mm spaced electrodes, the resistance of Pyralene is about 10^{13} Ω/cm/cm².

3.3.4. — **Factors influencing the electrical properties :**

All the electrical properties of Pyralene, substances of a resinous structure, are governed by the rule of polarity as shown by Debye in his theory of permanent dipoles.

The polar properties of Pyralene explain their behaviour in relation to heat and the frequency to which they are submitted.

a) *Influence of temperature* (fig. 1).

Generally, an increase in temperature brings about an increase in losses and a decrease of the dielectric constant and resistivity. Losses, in this case, are usually due to conductivity. The curve of the tangent of the loss angle (tang. δ) in relation to temperature, when hot, is a curve which is very close to that of the fluidity of the liquid. These losses are, in effect, caused by very small quantities of ionisable impurities which might have been dissolved in the liquid, and the mobility of the ions is reduced by the viscosity of the liquid. As by heating the fluidity is increased the losses increase more or less in the same ratio. Earth treatments reduce these losses.

If, on the contrary, Pyralene 1476 is cooled to complete solidification, a sharp increase in losses and a rapid decrease in the dielectric constant in the region of the solidifying point will be noticed then the losses revert to normal and the dielectric constant tends towards its optical value (square of the refractive index). These losses are due to the hindrance of the orientation of the dipoles in the alternating field by the viscosity.

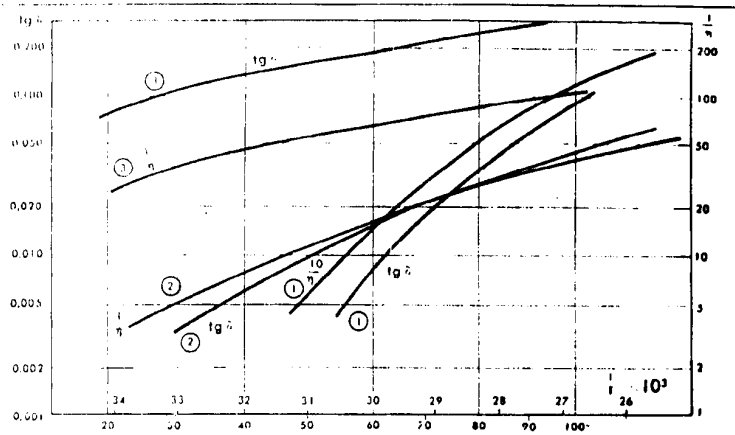
This phenomenon, known as anomalous dispersion, occurs also with the other Pyralenes, but at much lower temperatures. (Lower than — 50°C for Pyralene 1477).

b) *Influence of frequency* : (fig. 2).

Low viscosity Pyralene is practically unaffected by the frequency of the current, when cold, and in the low frequency field. However, losses, when hot, undergo a variation which is approximately inverse to frequency : for instance, passing from a frequency of 50 c/s to 500 c/s divides the losses, when hot, by a factor of approximately 10. Impurities act as a shunt resistance in the liquid capacitor.

Pyralene 1476 on the other hand shows a maximum of losses for a given frequency and temperature. This maximum corresponds to that of the anomalous dispersion. The higher the temperature, the higher the frequency at which the dispersion occurs. These losses are of a molecular nature and earth treatment has no effect on them.

The dielectric constant also drops sharply and tends towards its optical value.



Comparison between the variation of tg δ and the variation of fluidity versus temperature for chlorinated liquids of various viscosities.

1) High viscosity liquid (2) Medium viscosity liquid (3) Low viscosity liquid

Fig. 1

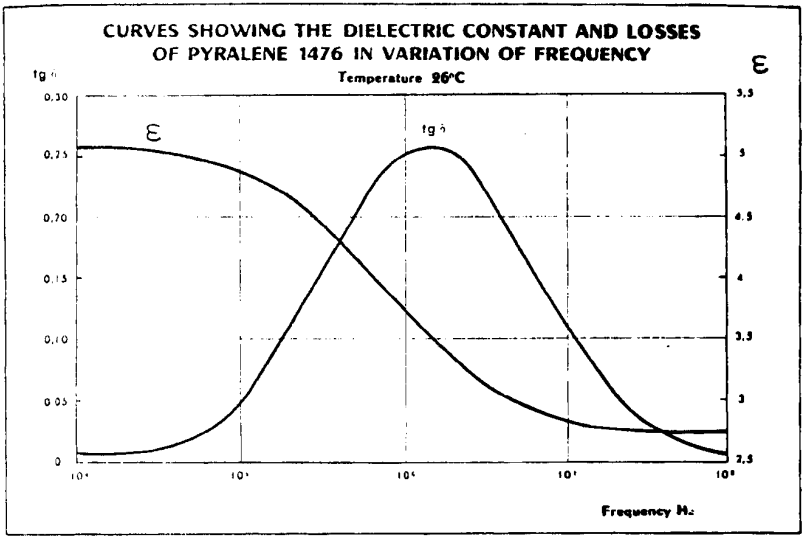


Fig. 2

c) *Influence of impurities* :

Acidity, alkanity or the presence of foreign substances in suspension decreases the dielectric quality of Pyralenes. An increase of losses is noticed. As Pyralene has a high dielectric constant and the ionizing power of the solvents increase approximately in an exponential manner in relation to the dielectric constant, relatively small quantities of dissolved impurities give the liquid high losses. Hence Pyralenes must be carefully manipulated, they should not be used in the presence of materials which might contaminate them.

Note that contaminated Pyralenes can retain a very high dielectric strength (over 200 kV/cm) whilst also having high dielectric losses (0.3).

d) *Influence of humidity* :

Absorption of moisture decreases the dielectric strength of Pyralene ; however, this drop of dielectric strength, for the same quantity of water absorbed is much lower than in the case of new mineral oil ; besides an oil that has been used shows an increase in its capacity to absorb moisture which causes a still more rapid decrease of the dielectric strength.

3.4 — PHYSIOLOGICAL EFFECTS :

Under normal conditions of use, Pyralenes can be handled without risk of toxic effects.

The user is particularly recommended :

— to provide ventilation when opening up the impregnating autoclaves or to allow them to cool down to 50-60° C so as to avoid releasing too large a volume of vapours which are unpleasant to inhale an can have an irritating effect on the mucous membranes.

— avoid spilling hot Pyralene on the skin, which might cause some irritation. This irritation disappears by washing with soap or rubbing with glycerine.

4 — INDUSTRIAL USES OF PYRALENE

4.1 — TRANSFORMERS

The use of Pyralene in transformers gives the following advantages :

— safety

— economy.

SAFETY : Pyralene is non inflammable and its vapours are non explosive.

It is recommended for transformers, used in mines, buildings, theatres, under-ground installations, underground railways, ships, locomotives and in all cases where the least risk of fire can be tolerated.

ECONOMY : Such safety means an economy of space, materials, cost, erection time and operating cost.

Economy of space : Use can be made of waste place (underground underroof, etc.) to house Pyralene transformers.

Economy of materials and erection time : Pyralene does away with anti-fire enclosures or concrete vaults which are essential in the case of oil transformers. Fire equipment and an oil draining tank are also no longer required.

Finally Pyralene transformers are indispensable auxiliaries for power distribution throughout work-shops and are systematically replacing distribution via a single sub-station.

Comparison, for equal power, between a central station (enclosure with an oil transformer) and four stations which are spread out (pre-fabricated stations with Pyralene transformers), designed for distributing 2.500 kVA at 15 kV per work-shop having a length of 245 yards and 130 yards width, gave the following comparison :

— *for the central sub-station* : 2.500 kVA oil transformer : price 100 per cent;

— *for 4 transformer stations* : with Pyralene transformers each rated at 630 kVA : price 82 per cent.

It must not be forgotten that because it is possible to erect Pyralene transformers at the load centre, it is also possible to effect a large economy in low voltage cables and in their installation, their cost, per yard installed, for a load of 1.000 kVA varying as follows :

— A 380 V : 100 per cent.

— B 15.000 V : 13 per cent.

Bearing in mind the saving of time required for erection the total economy realised can in certain cases reach 40 per cent.

Economy of power : having high voltage at the load centre leads to a large economy of cable leakage.

Moreover, the voltage drop in low voltage cables is greatly reduced : It is well known that the torque of an asynchronous motor varies as the square of the voltage and that certain types of electric equipment require, to ensure correct operation and an acceptable valve life, a voltage having less than 5 per cent variations.

Economy in maintenance : Maintenance of Pyralene transformers is practically nil; Pyralene does not require any of the periodical treatments as does mineral oil.

Very important : The advantages of Pyralene transformers **have been recognised in France** by Fire Insurance Companies who, by their notifications N° 573 and 574, **considerably reduce insurance** premiums of electrical installations equipped with transformers **immersed in Pyralene.**

4.2 — CAPACITORS

4.2.1. — **The high dielectric constant of Pyralenen twice that of oil gives :**

— increase in capacity : For equal volumes, **the increase in capacity of a capacitor impregnated with** Pyralene against one impregnated with oil is **approximately 40 per cent.**

For a given capacity, the use of Pyralene yields therefore **an important economy of aluminium,** paper and labour which can amount to approximately 20 per cent.

— a better distribution of the electrostatic field between **the electrodes : The voltage gradient to which** each of two insulators in series is subjected is **inversely proportional to the respective dielectric** constants of each of the two insulators.

In the paper-pyralene complex, **the liquid insulator will be under lower voltage stress than the** liquid in the paper-oil complex. With a **voltage gradient of 15 V per micron applied to the** impregnated paper dielectric, the voltage stress resulting in **Pyralene will only be 20 V per micron,** as against 26 V per micron for oil.

4.2.2. — **High dielectric strength :**

Because this is clearly higher than that of **mineral oil, it allows an increase in the voltage gra**dient employed : this can be 1,5 times more than in the case of **mineral oil capacitors, taking into account** an equal safety factor.

In fact, in most applications, **an increase in the safety factor will be preferred, and thereby the** life of the Pyralene impregnated capacitor will be **lengthened.**

4.2.3. — **Chemical stability :**

Pyralene is insensitive to the action of intense **electrical fields which do not therefore give rise** to any polymerisation.

Mineral oil, on the contrary, by polymerisation **gives rise to the formation of a wax, called** " Wax X " which may lead to rapid deterioration of **the capacitor by decreasing considerably its ioni**sation voltage.

4.2.4. — **Non-inflammability :**

4.2.5. — **The advantages of Pyralene capacitors, viz :**

— small bulk;

— low losses;

— high stability;

— non-inflammability;

lead to this dielectric being used for many different types of capacitors :

to improve the power factor, low and high voltage (units up to 100 kVAR);

capacitors for fluorescent tubes;

— capacitors for radio transmitters, radar delay cables, shock generators;

— coupling capacitors, voltage dividers, (high voltage cables);

— medium frequency capacitors for induction furnaces, etc.

Pyralene impregnated capacitors comply with the official specification.

4.3. — CABLES

Pyralene 1476 and 1482 make, on the other hand, excellent co-plasticisers of polyvinyl chloride insulated cables : Pyralene gives :

— a better resistance to fire,

— greatly improved insulating properties (electrical resistance) which are usually greatly decreased when adding other plasticisers. (See our pamphlet P-35).

4.4 — OTHER APPLICATIONS

Pyralene are also used as liquid dielectrics for :

— Selenium rectifiers;

— Instrument transformers;

— Voltage regulators;

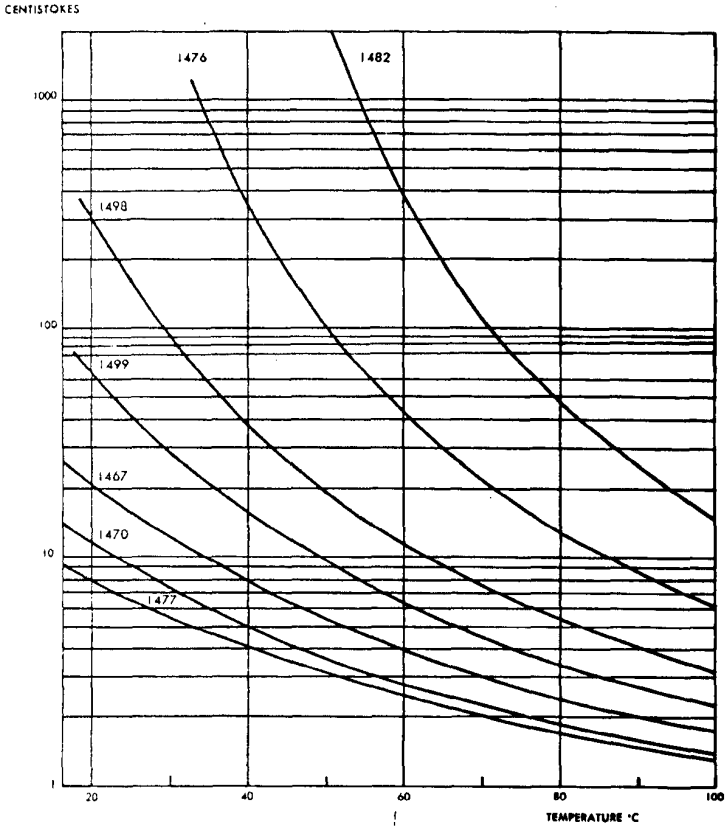
— Induction coils;

— Rheostats;

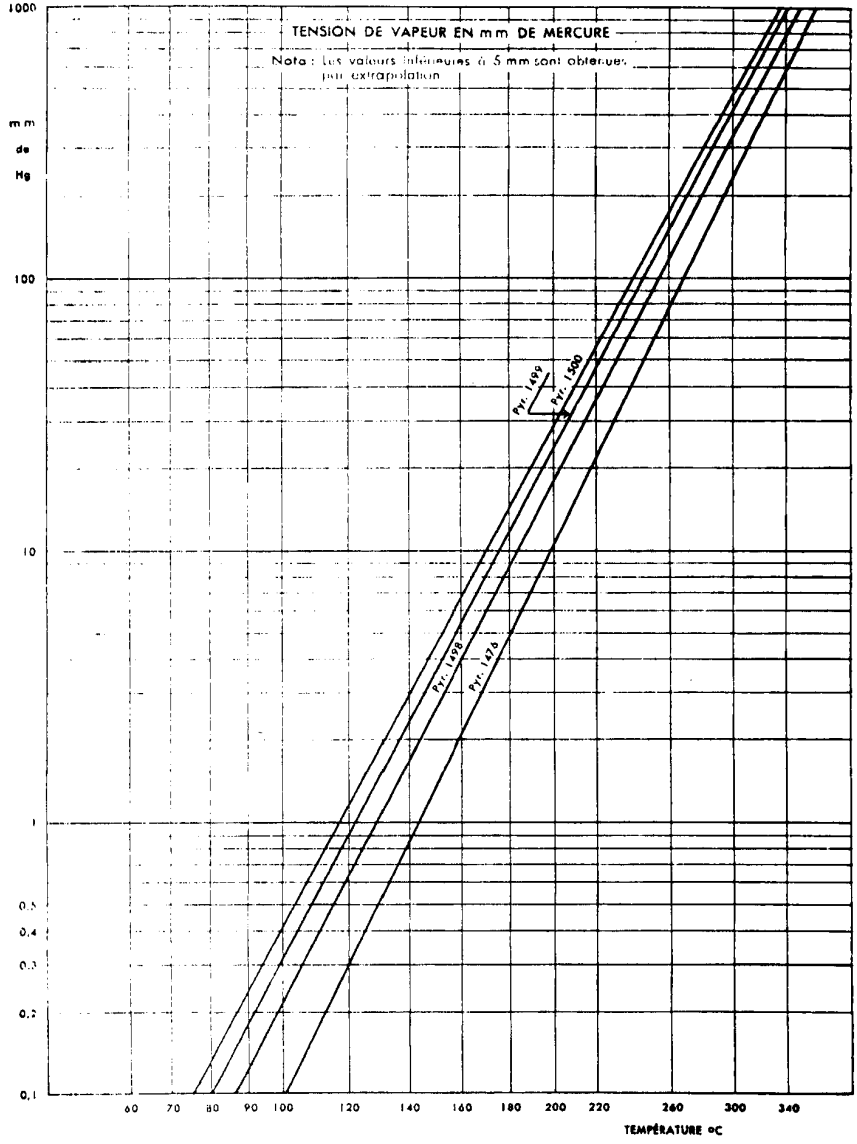
— etc.

Let us also mention their use as heating liquids (pyralenes 1498 and 1476) up to 280°C.

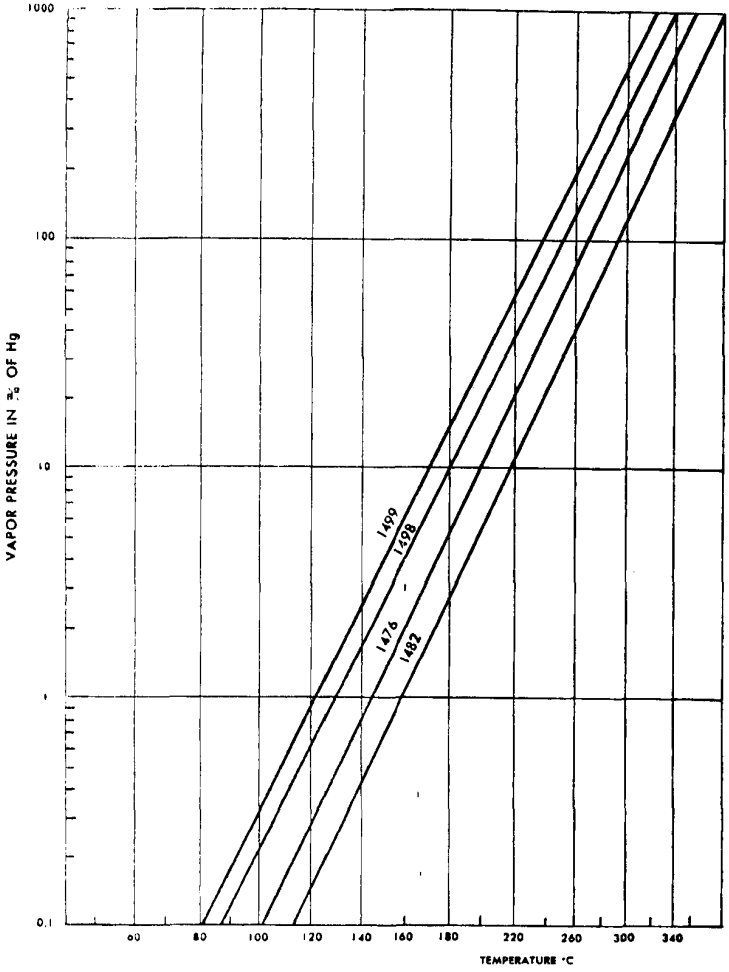
KINEMATIC - VISCOSITY OF PYRALENE VS. TEMPERATURE



PYRALÈNE POUR CONDENSATEURS



VAPOR PRESSURE OF PYRALENE VS. TEMPERATURE



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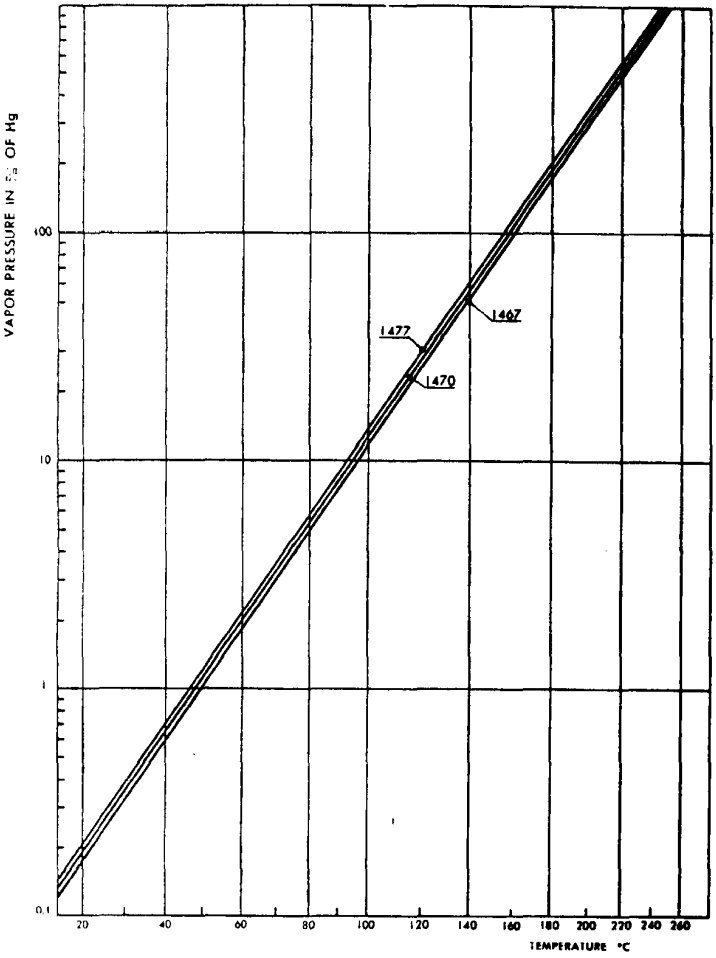
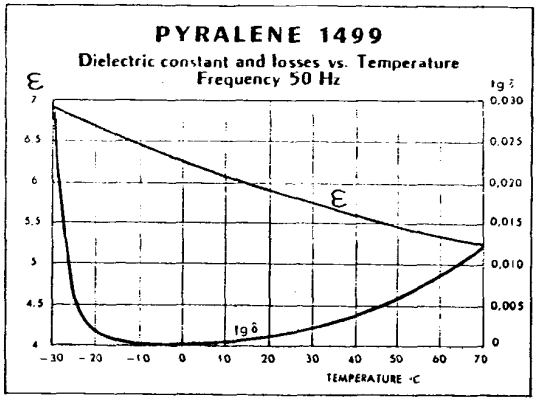
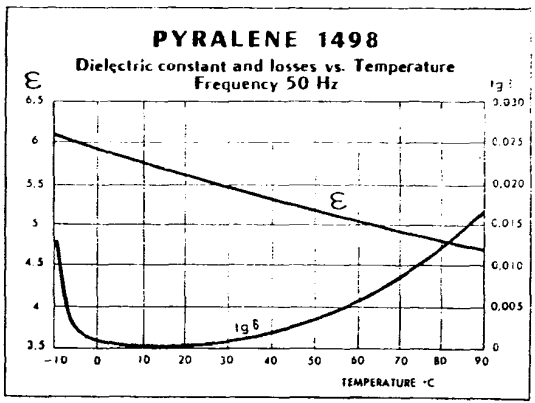
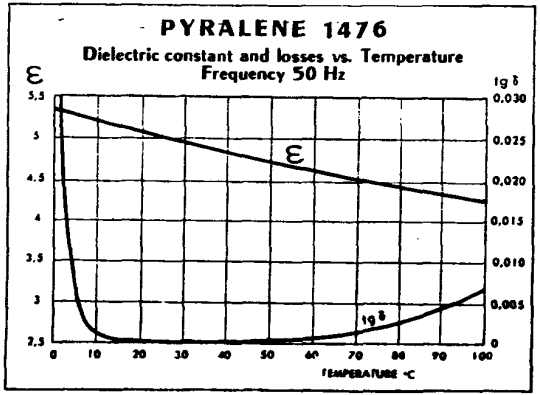
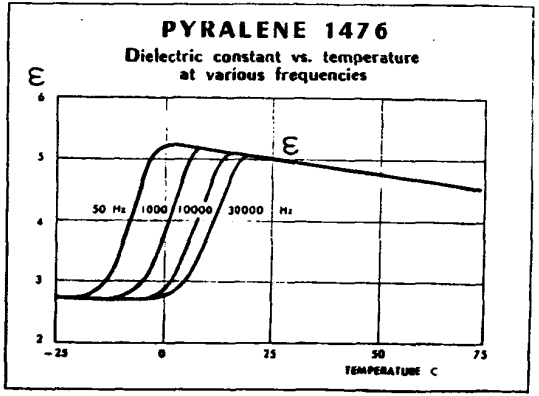



PYRALENE 1499
Dielectric constant and losses vs. Temperature
Frequency 50 Hz
ε
tg δ
7
6.5
6
5.5
5
4.5
4
0.030
0.025
0.020
0.015
0.010
0.005
0
ε
tg δ
−30 −20 −10 0 10 20 30 40 50 60 70
TEMPERATURE °C

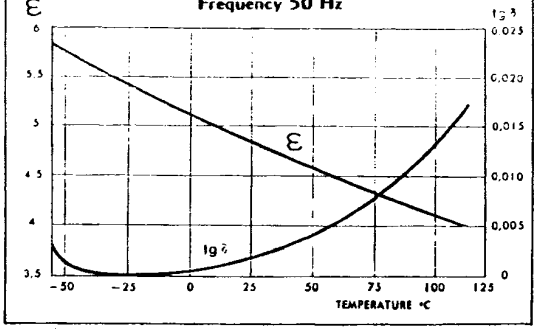

PYRALENE 1498
Dielectric constant and losses vs. Temperature
Frequency 50 Hz
ε
tg δ
6.5
6
5.5
5
4.5
4
3.5
0.030
0.025
0.020
0.015
0.010
0.005
0
ε
tg δ
−10 0 10 20 30 40 50 60 70 80 90
TEMPERATURE °C


PYRALENE 1476
Dielectric constant and losses vs. Temperature
Frequency 50 Hz
ε
tg δ
5.5
5
4.5
4
3.5
3
2.5
0.030
0.025
0.020
0.015
0.010
0.005
0
ε
tg δ
0 10 20 30 40 50 60 70 80 90 100
TEMPERATURE °C


PYRALENE 1476
Dielectric constant vs. temperature
at various frequencies
ε
6
5
4
3
2
ε
50 Hz
1000
10000
30000
Hz
−25 0 25 50 75
TEMPERATURE C

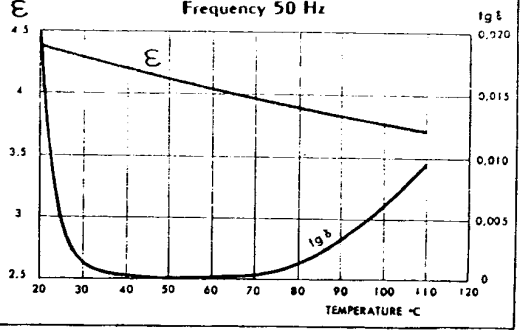
PYRALENE 1477

Dielectric constant and losses vs. Temperature
Frequency 50 Hz



PYRALENE 1482

Dielectric constant and losses vs. Temperature
Frequency 50 Hz



PYRALENE 1476

Dielectric losses tg δ vs. temperature
at various frequencies