



## Experimental study on the thermal degradation of insulating oil / Kraft paper by DGA

### Introduction

In Labelec, we have recently carried out a Kraft paper / insulating oil dynamic ageing experiment, in order to study the mechanism of thermal degradation of cellulosic paper and insulating oil used in the construction of transformers.

The ageing experiment was carried out in controlled laboratory conditions, according with a plan of work established by CIGRÉ task force 15-01-05.

The following material and equipment were used for conducting the experiment:

**Paper** - Kraft paper transformer grade supplied by ABB Switzerland.

The Kraft paper was wrapped in 3 layers to about a length of 5 cm of copper conductor.

The paper should be dried previously to have a moisture content of less than 0,5%.

**Mineral oil** - Mineral insulating oil (in this case, Nynas Nytro 11EN, an uninhibited oil) at which we added DBPC (0,3%) and Benzotriazol (25mg/kg<sub>oil</sub>).

The oil was dried just before the beginning of the experiment, in order to obtain a moisture content of < 5 ppm. This was achieved by bubbling dry nitrogen for 2 hours, into the oil. Afterwards the oil was saturated with air, by bubbling dry air, for one hour, into the oil.

**Reaction vessel** - The ageing vials had a capacity of about 150 ml and were made from borosilicate glass with about 3,8 cm of diameter and 20 cm of height.

The vial has a narrow neck with about 1 cm diameter and 4 cm length.

All glass vials were cleaned (washed with water and acetone) and dried at 100°C before use.

We used 2 pieces of copper conductor (5×0,5×0,1 cm) each one wrapped with 3 layers of paper, inside each glass ampoule, containing about 100 ml of oil.

For each temperature (except for the temperatures of 70, 80 and 90 °C), we have used 2 ampoules with oil and paper and 1 ampoule only with oil (blank).

For the temperatures of 70, 80 and 90 °C, we used just 1 ampoule with oil and paper and 1 ampoule only with oil (blank).

**Sample preparation** – We introduced the paper wrapped conductor into the vial, using a tweezers, and then we placed the vial in a vacuum oven and apply heat and vacuum. The oven was set at 80°C and we left the vials over night under vacuum and heat. Then, the vials containing the dried paper were left to cool down to room temperature in a desiccator. After we introduced about 100 ml of air saturated oil into the vial. Afterwards, we sealed the narrow neck of the vial using a flame torch. We also prepared blank oil samples containing only oil in similar manner.

In this case, the ratio paper/oil in weight was 625.

**Ageing procedure** – We have placed the samples in a fan forced oven at 70°C and after 24 h at this temperature, we have increased 10°C, maintaining this temperature for another period of 24 h.

We have repeated this increase of 10°C each 24 hours, until the end of the experiment, which finished at the temperature of 180°C.

The ampoules remained also during 24h at each temperature and we have removed one set of sample and blank daily from the oven, until the temperature of 180°C is reached.

Finally, we let the vials to cool down to room temperature in the dark (to avoid further ageing due to sunlight), cut the neck of each vial and besides other tests, we have also performed the dissolved gas analysis (DGA) in the oil, which results we are going to report here.

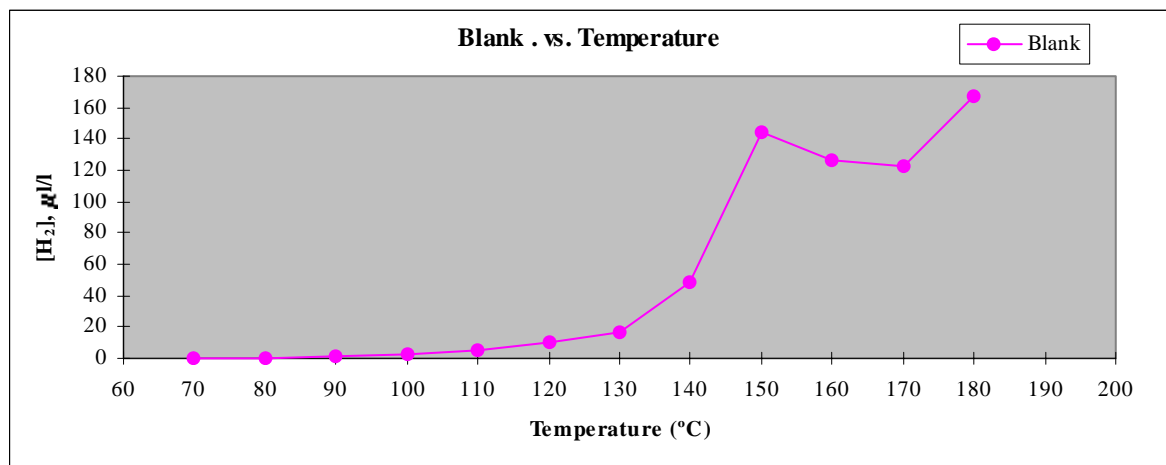
So for **mineral insulating oil (Nynas Nytro 11EN)**, the experimental **DGA results** were the following:

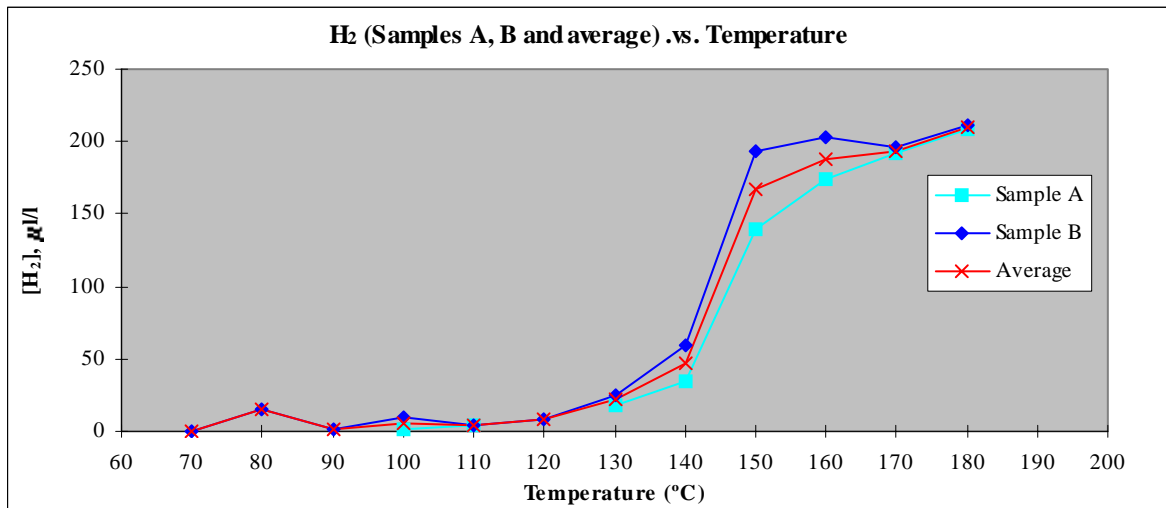
## Part 1 – Mineral insulating oil (Oil Nynas Nytro 11 EN)

DGA results: (determined by IEC 60567)

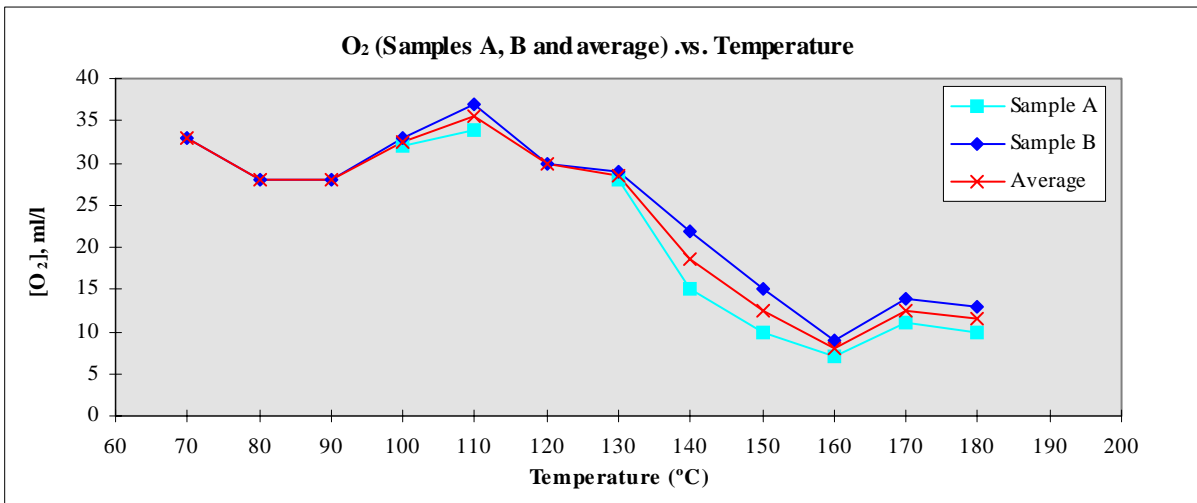
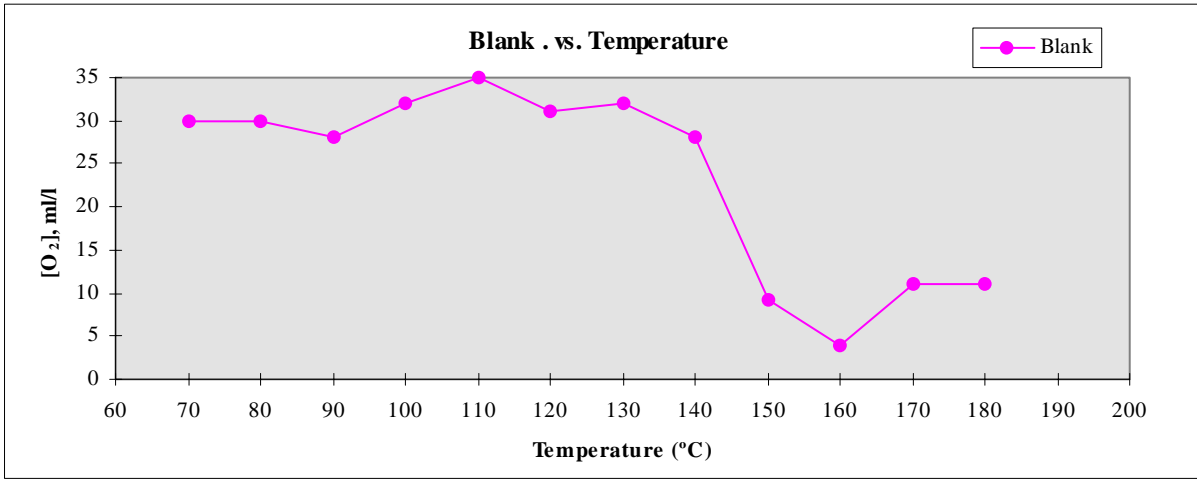
Temperature °C	H <sub>2</sub> , I/l				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 5 (*)	< 5	< 4 (*)	-
80	---	15	15	< 4 (*)	-
90	---	< 4 (1)	< 4 (1)	< 4 (1)	-
100	< 5 (1)	10	6	< 5 (2)	4
110	< 5 (4)	< 6 (4)	4	5	-1
120	---	8	8	10	-2
130	18	25	22	16	6
140	34	59	46	48	-2
150	140	193	166	144	22
160	174	203	188	126	62
170	192	196	194	122	72
180	209	211	210	167	43

(\*) - Not found.

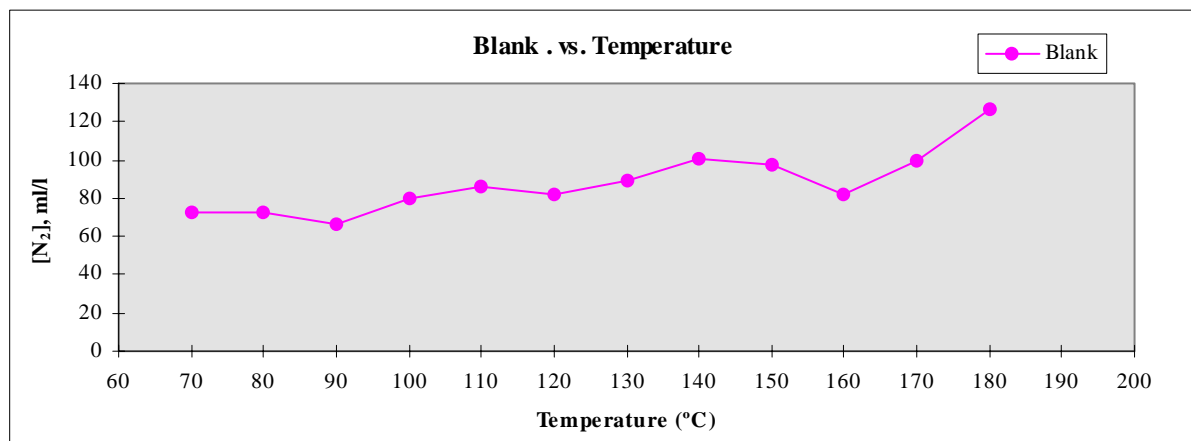


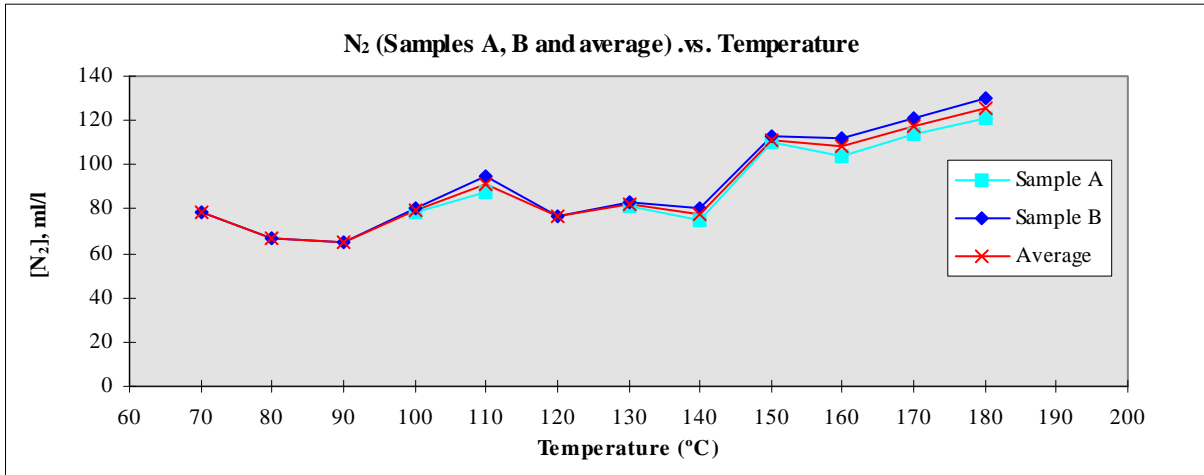


Temperature °C	O <sub>2</sub> , ml/l				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	33	33	30	3
80	---	28	28	30	-2
90	---	28	28	28	0
100	32	33	32	32	0
110	34	37	36	35	1
120	---	30	30	31	-1
130	28	29	28	32	-4
140	15	22	18	28	-10
150	10	15	12	9	3
160	7	9	8	4	4
170	11	14	12	11	1
180	10	13	12	11	1

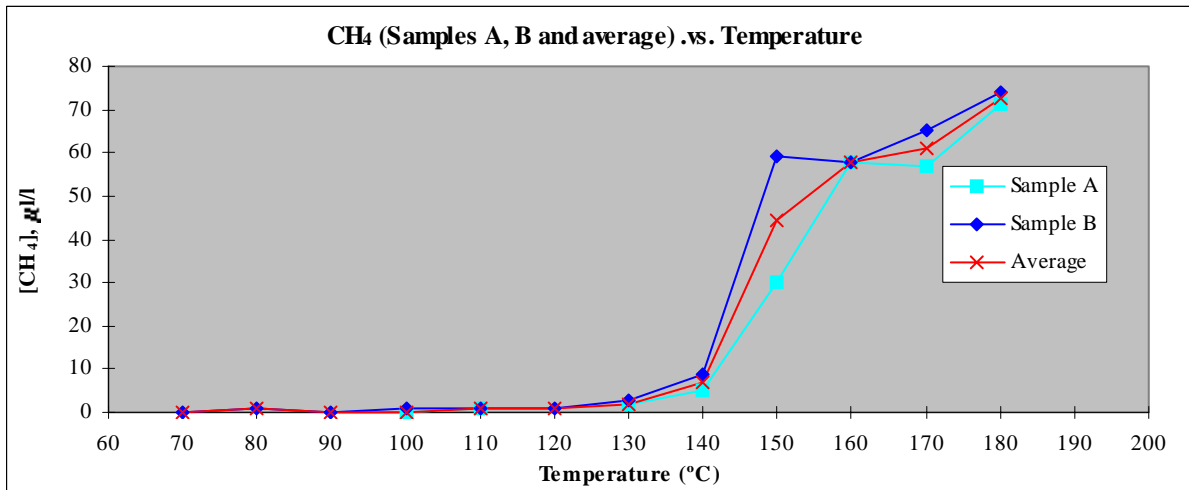
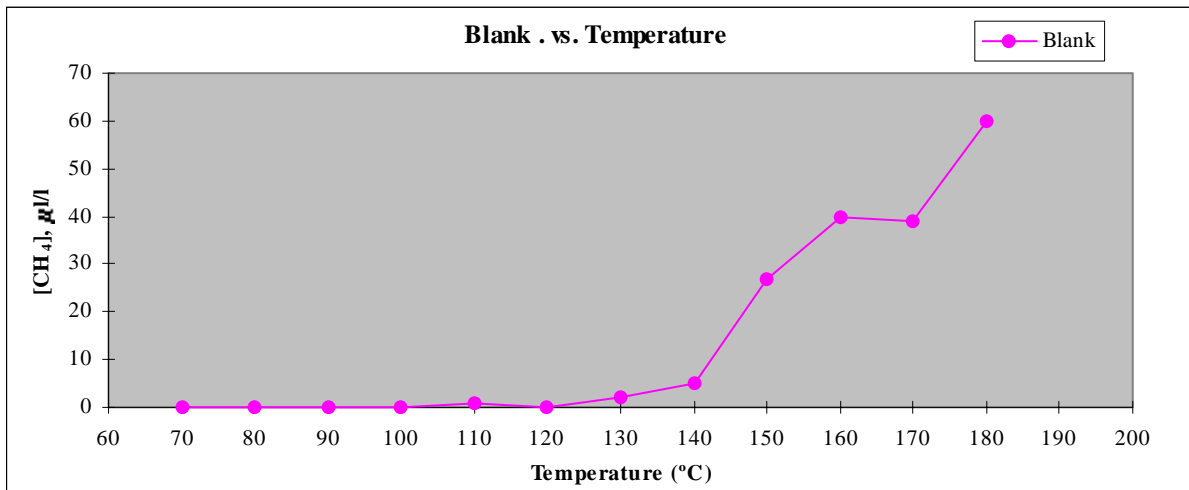


Temperature °C	N <sub>2</sub> , ml/l				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	79	79	73	6
80	---	67	67	73	-6
90	---	65	65	66	-1
100	79	80	80	80	0
110	88	95	92	86	6
120	---	77	77	82	-5
130	81	83	82	89	-7
140	75	80	78	101	-23
150	110	113	112	98	14
160	104	112	108	82	26
170	114	121	118	100	18
180	121	130	126	127	-1



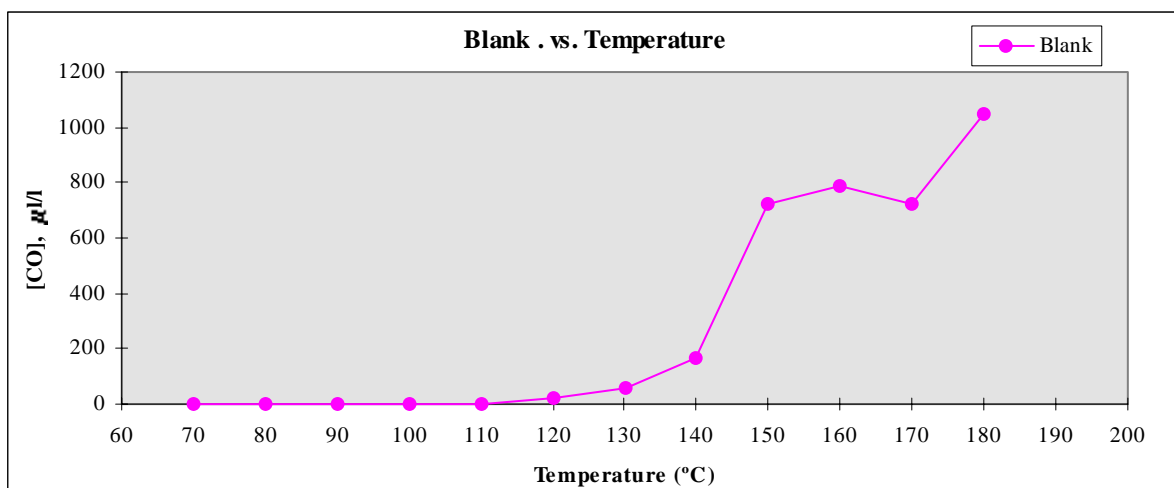


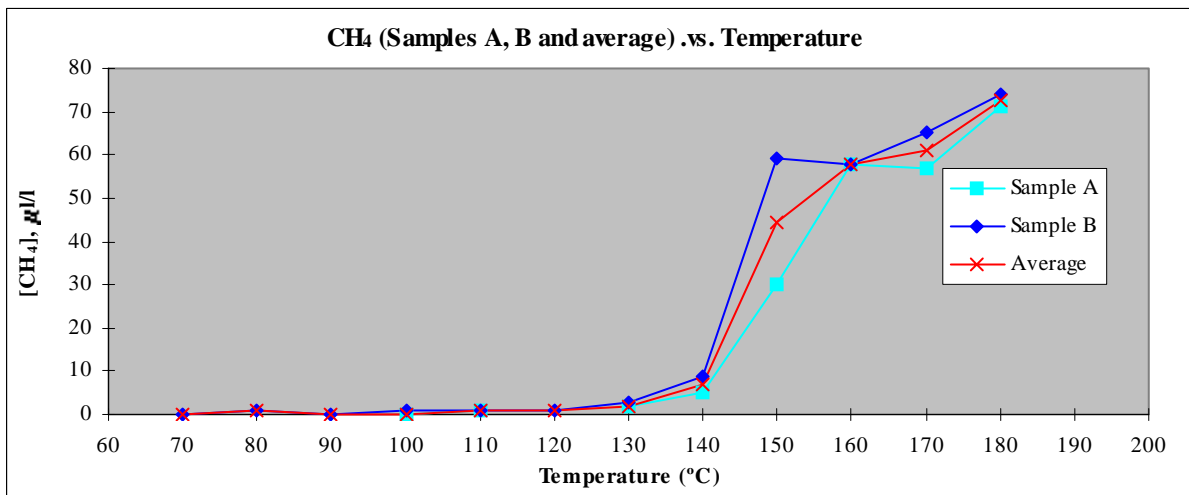
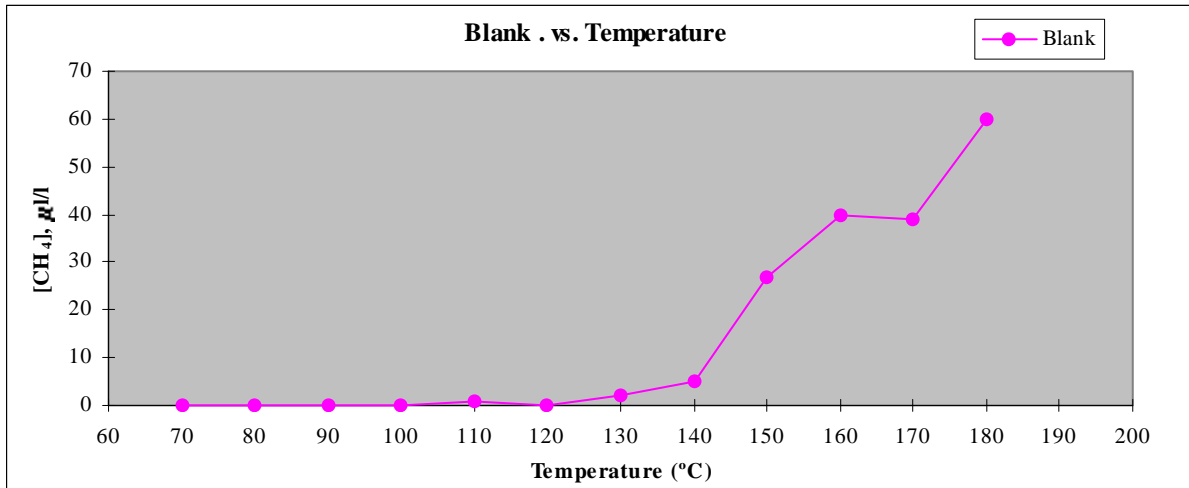
Temperature °C	CH <sub>4</sub> , l/l				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 1	< 1	< 1	-
80	---	1	1	< 1	-
90	---	< 1	< 1	< 1	-
100	< 1	1	< 1	< 1	-
110	1	1	1	1	-
120	---	1	1	< 1	-
130	2	3	2	2	0
140	5	9	7	5	2
150	30	59	44	27	17
160	58	58	58	40	18
170	57	65	61	39	22
180	71	74	72	60	12



Temperature °C	CO, I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 30 <sup>(*)</sup>	< 30	< 28 <sup>(*)</sup>	-
80	---	35	35	< 28 <sup>(*)</sup>	-
90	---	< 25 <sup>(*)</sup>	< 25	< 25 <sup>(*)</sup>	-
100	< 30 <sup>(*)</sup>	< 30 (25)	< 30	< 30 <sup>(*)</sup>	-
110	< 35 (8)	< 33 (13)	10	< 33 (3)	7
120	---	56	56	< 30 (19)	37
130	142	161	152	57	95
140	177	427	302	167	135
150	748	1050	899	720	179
160	1084	1129	1106	789	317
170	1079	1080	1080	726	354
180	1308	1338	1323	1048	275

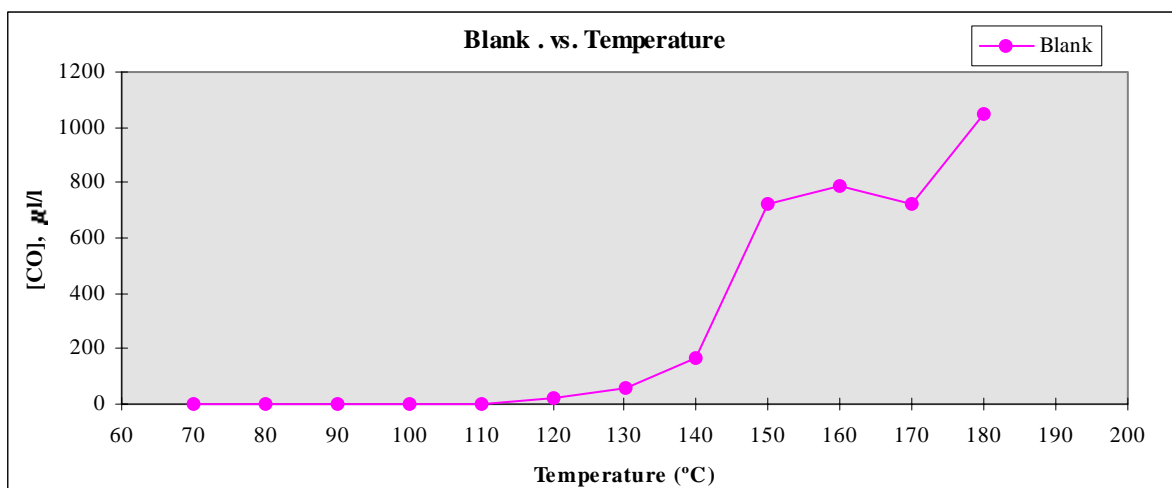
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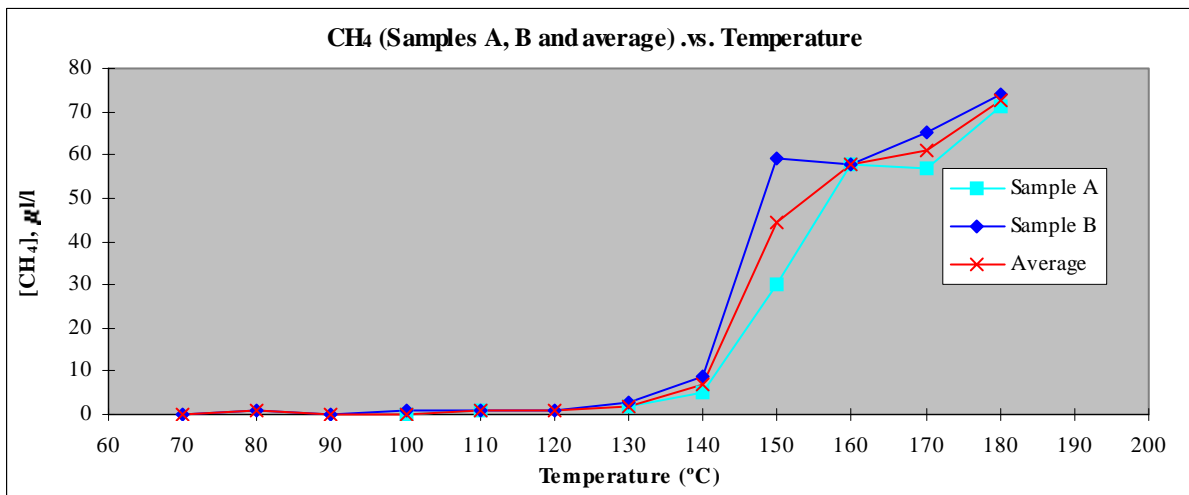
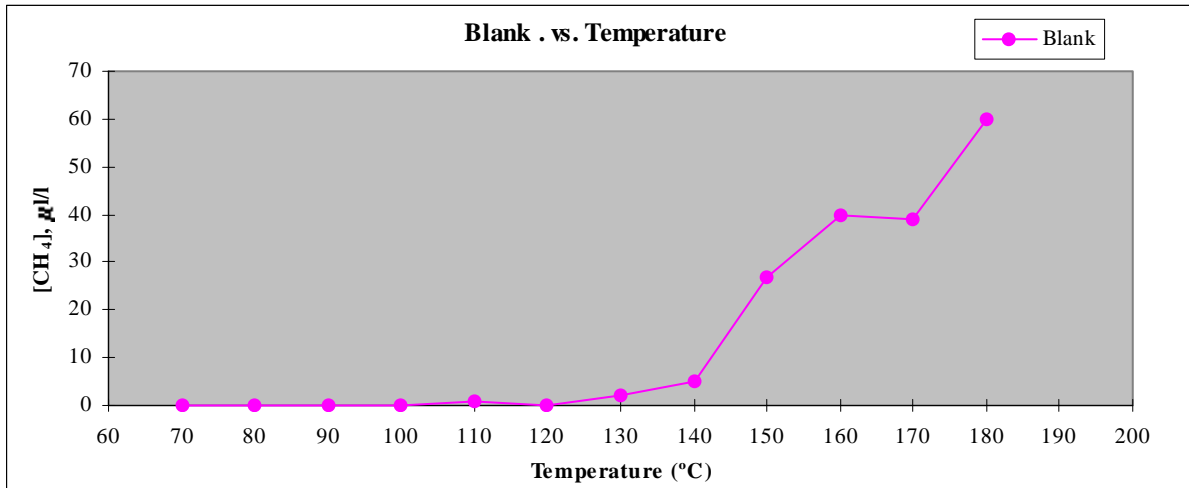




Temperature °C	CO, I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 30 <sup>(*)</sup>	< 30	< 28 <sup>(*)</sup>	-
80	---	35	35	< 28 <sup>(*)</sup>	-
90	---	< 25 <sup>(*)</sup>	< 25	< 25 <sup>(*)</sup>	-
100	< 30 <sup>(*)</sup>	< 30 (25)	< 30	< 30 <sup>(*)</sup>	-
110	< 35 (8)	< 33 (13)	10	< 33 (3)	7
120	---	56	56	< 30 (19)	37
130	142	161	152	57	95
140	177	427	302	167	135
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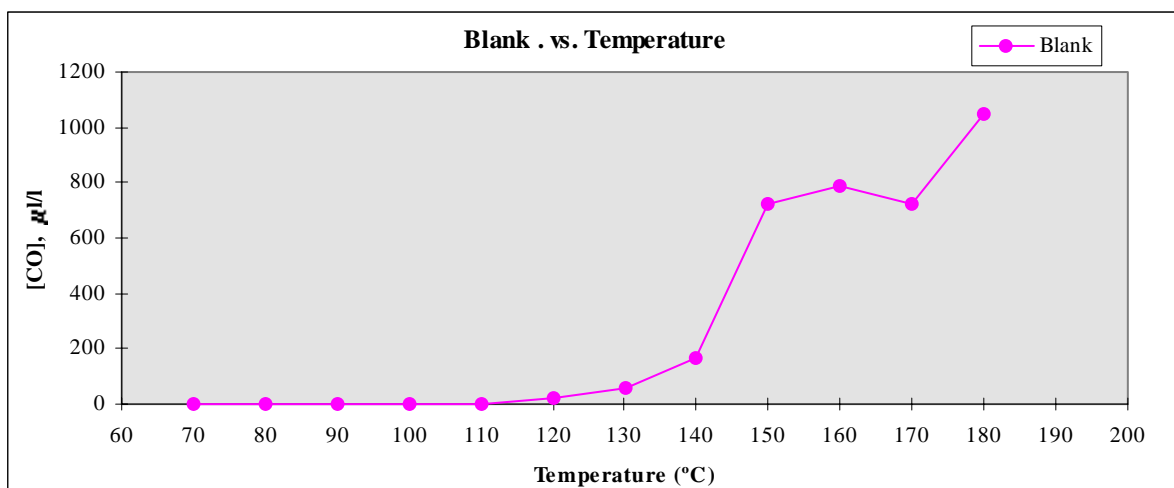
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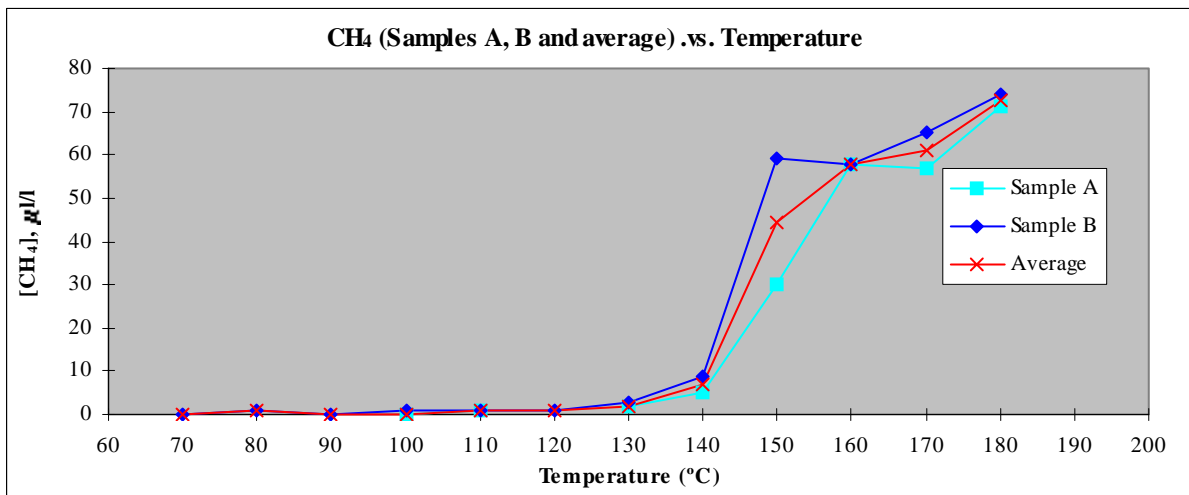
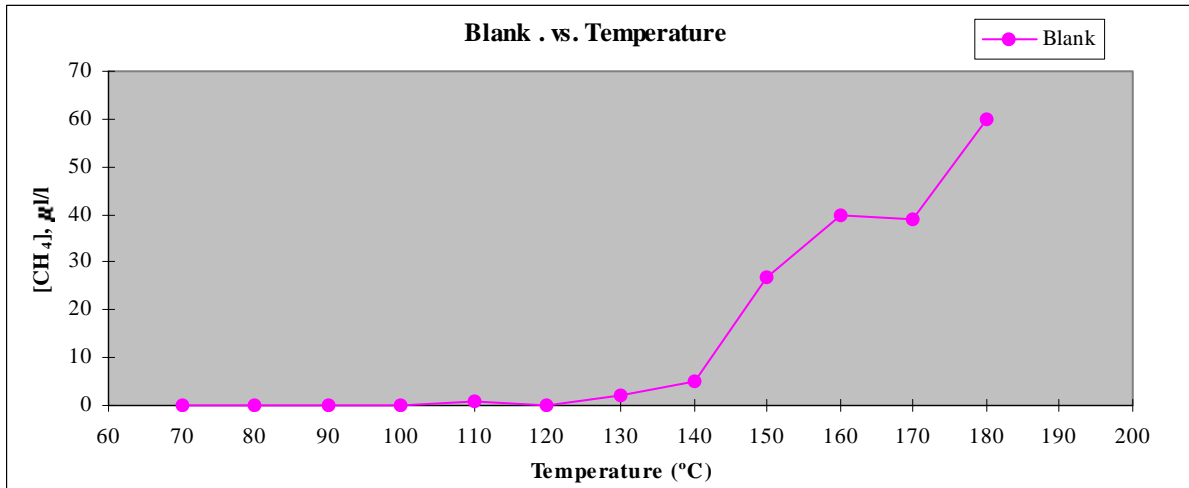




Temperature °C	CO, I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 30 <sup>(*)</sup>	< 30	< 28 <sup>(*)</sup>	-
80	---	35	35	< 28 <sup>(*)</sup>	-
90	---	< 25 <sup>(*)</sup>	< 25	< 25 <sup>(*)</sup>	-
100	< 30 <sup>(*)</sup>	< 30 (25)	< 30	< 30 <sup>(*)</sup>	-
110	< 35 (8)	< 33 (13)	10	< 33 (3)	7
120	---	56	56	< 30 (19)	37
130	142	161	152	57	95
140	177	427	302	167	135
150	748	1050	899	720	179
160	1084	1129	1106	789	317
170	1079	1080	1080	726	354
180	1308	1338	1323	1048	275

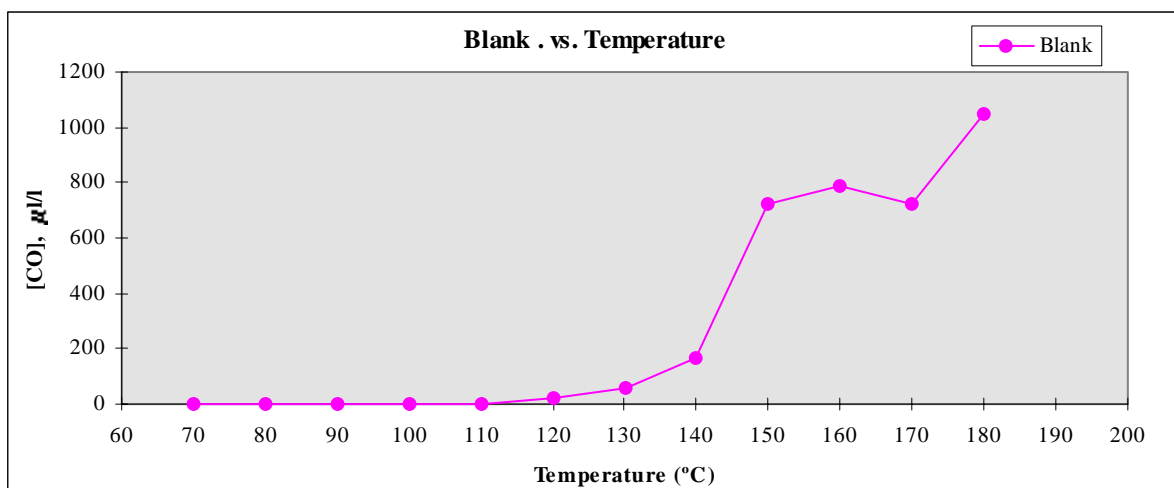
(\*) - Not found.

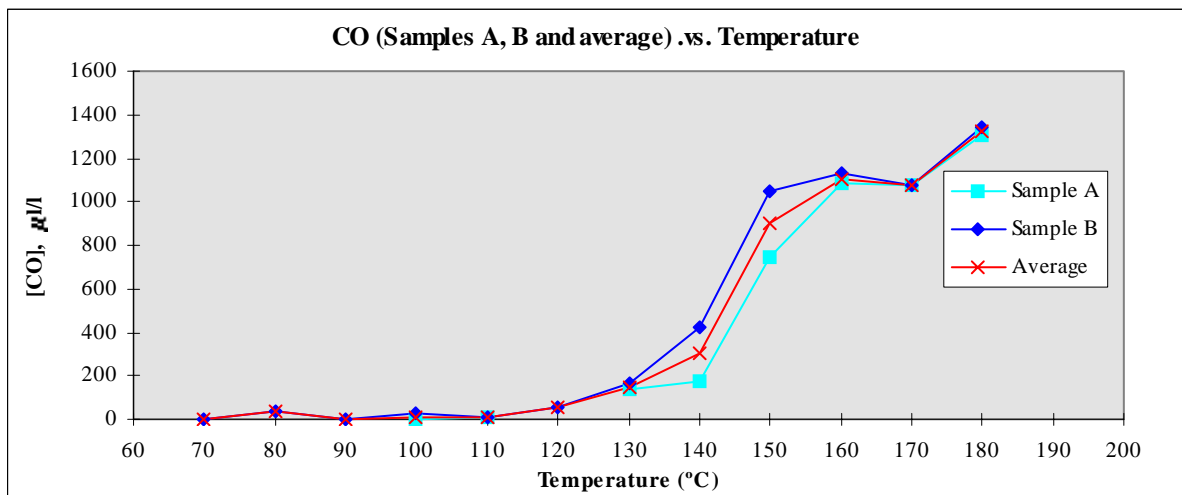




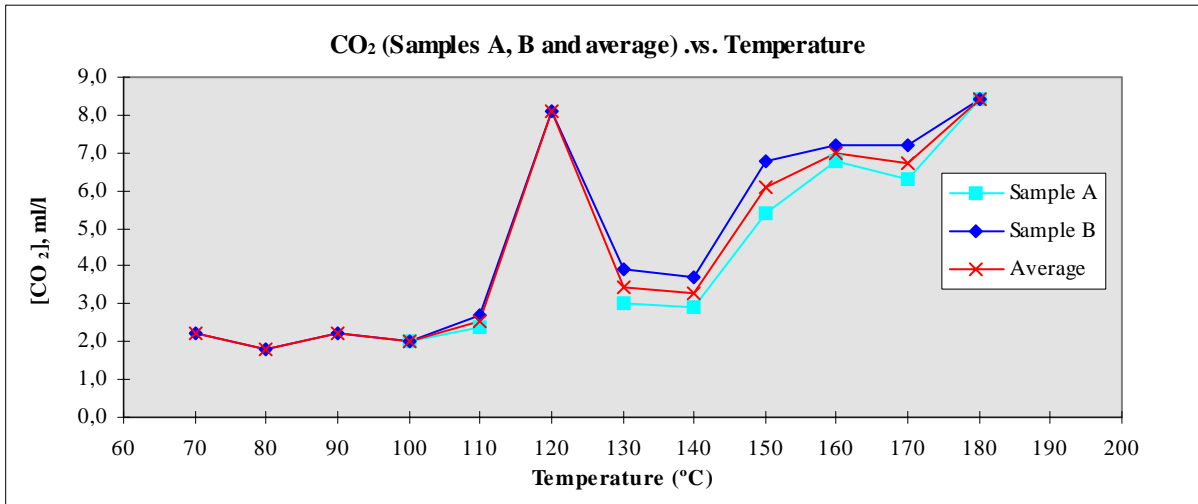
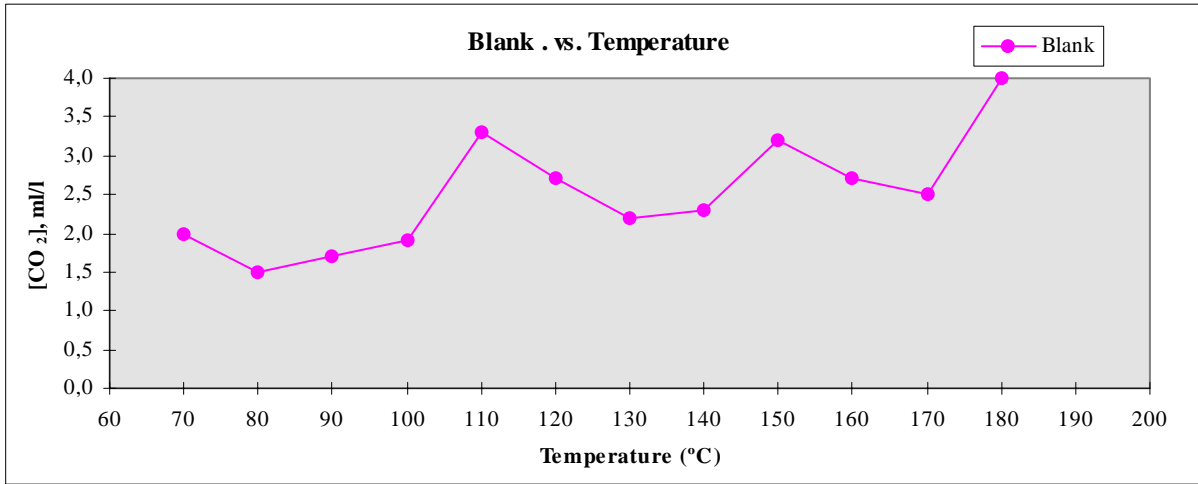
Temperature °C	CO, I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 30 <sup>(*)</sup>	< 30	< 28 <sup>(*)</sup>	-
80	---	35	35	< 28 <sup>(*)</sup>	-
90	---	< 25 <sup>(*)</sup>	< 25	< 25 <sup>(*)</sup>	-
100	< 30 <sup>(*)</sup>	< 30 (25)	< 30	< 30 <sup>(*)</sup>	-
110	< 35 (8)	< 33 (13)	10	< 33 (3)	7
120	---	56	56	< 30 (19)	37
130	142	161	152	57	95
140	177	427	302	167	135
150	748	1050	899	720	179
160	1084	1129	1106	789	317
170	1079	1080	1080	726	354
180	1308	1338	1323	1048	275

(\*) - Not found.

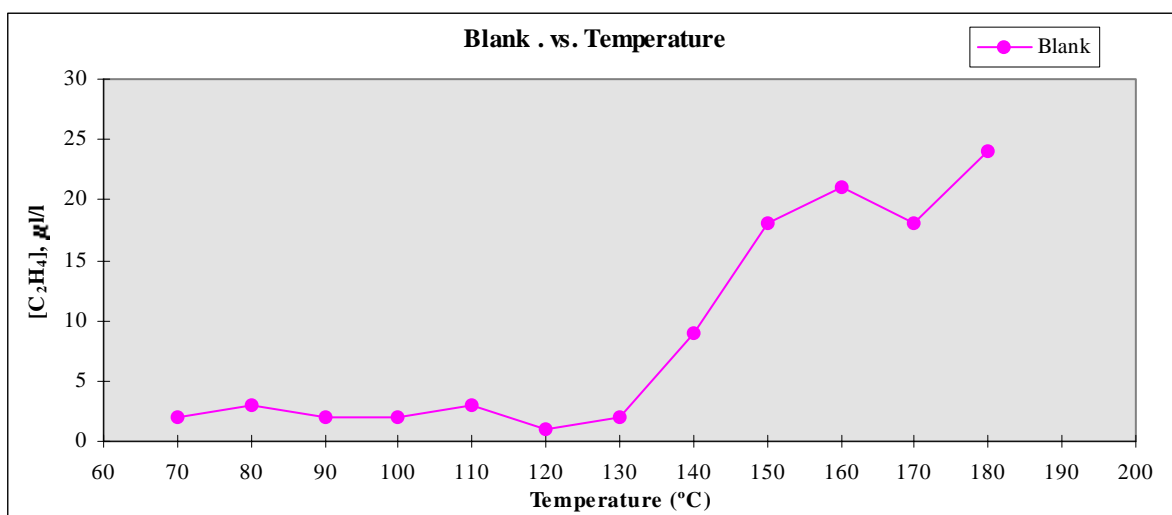


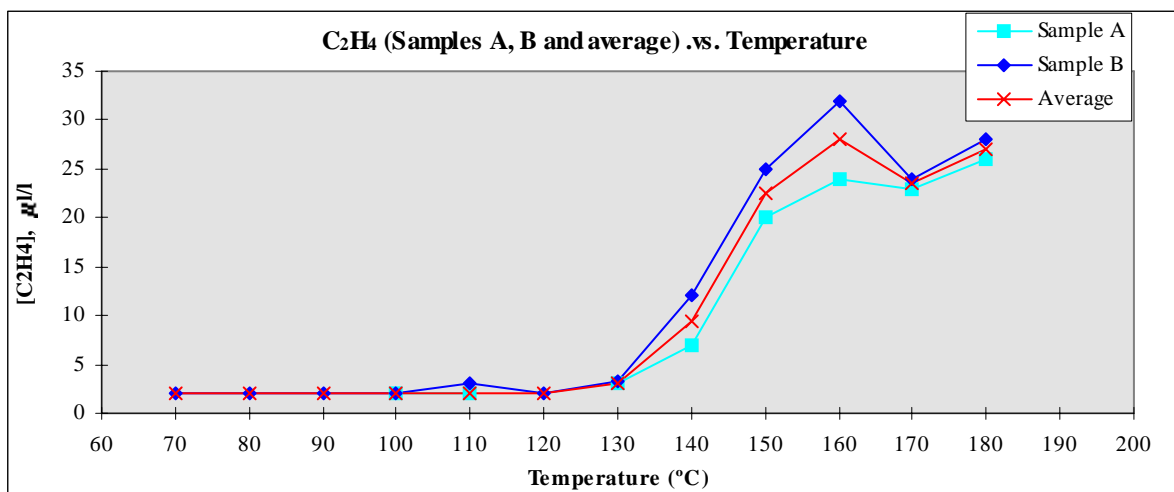


Temperature °C	CO <sub>2</sub> , ml/l				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	2,2	2,2	2,0	0,2
80	---	1,8	1,8	1,5	0,3
90	---	2,2	2,2	1,7	0,5
100	2,0	2,0	2,0	1,9	0,1
110	2,4	2,7	2,6	3,3	-0,7
120	---	8,1	8,1	2,7	5,4
130	3,0	3,9	3,4	2,2	1,2
140	2,9	3,7	3,3	2,3	1,0
150	5,4	6,8	6,1	3,2	2,9
160	6,8	7,2	7,0	2,7	4,3
170	6,3	7,2	6,8	2,5	4,3
180	8,4	8,4	8,4	4,0	4,4



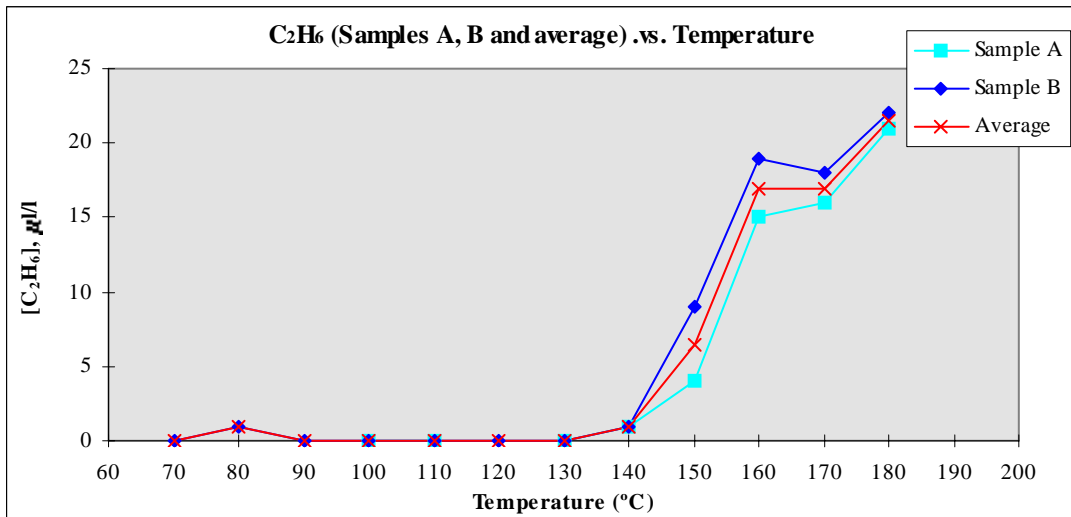
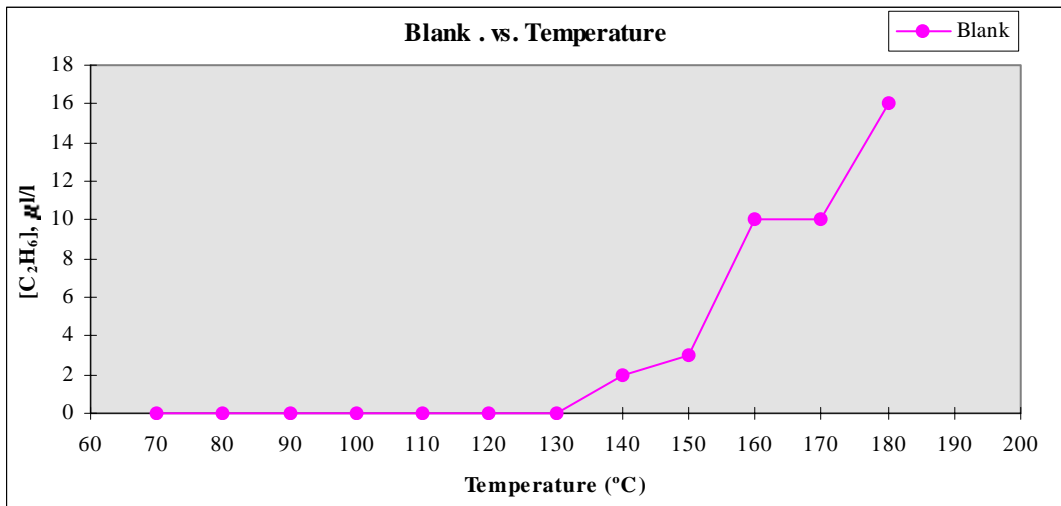
Temperature °C	C <sub>2</sub> H <sub>4</sub> , I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	2	2	2	0
80	---	2	2	3	-1
90	---	2	2	2	0
100	2	2	2	2	0
110	2	3	2	3	-1
120	---	2	2	1	1
130	3	3	3	2	1
140	7	12	10	9	1
150	20	25	22	18	4
160	24	32	28	21	7
170	23	24	24	18	6
180	26	28	27	24	3





Temperature °C	C <sub>2</sub> H <sub>6</sub> , I/I				
	Sample A	Sample B	Average	Blank	Average-Blank
70	---	< 1	< 1	< 1	-
80	---	1	1	< 1	-
90	---	< 1	< 1	< 1	-
100	< 1	< 1	< 1	< 1	-
110	< 1	< 1	< 1	< 1	-
120	---	< 1	< 1	< 1 <sup>(*)</sup>	-
130	< 1	< 1	< 1	< 1	-
140	1	1	1	2	-1
150	4	9	6	3	3
160	15	19	17	10	7
170	16	18	17	10	7
180	21	22	22	16	6

(\*) - Not found.



**C<sub>2</sub>H<sub>2</sub>** – Not found for both oils at all temperatures.

**Part 2 – Vegetable insulating oil (Oil BIOTEMP) vs mineral insulating oil (Oil Nynas Nytro 11 EN)**

We also repeated this experiment using a vegetable insulating oil, instead of a mineral oil (in this case the BIOTEMP oil), and have obtained the following DGA results.

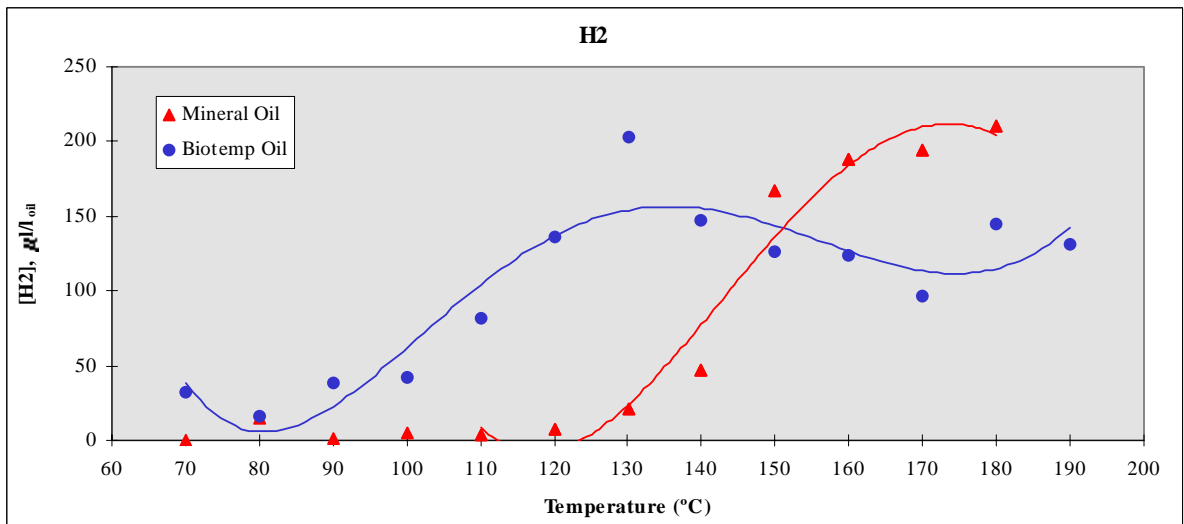
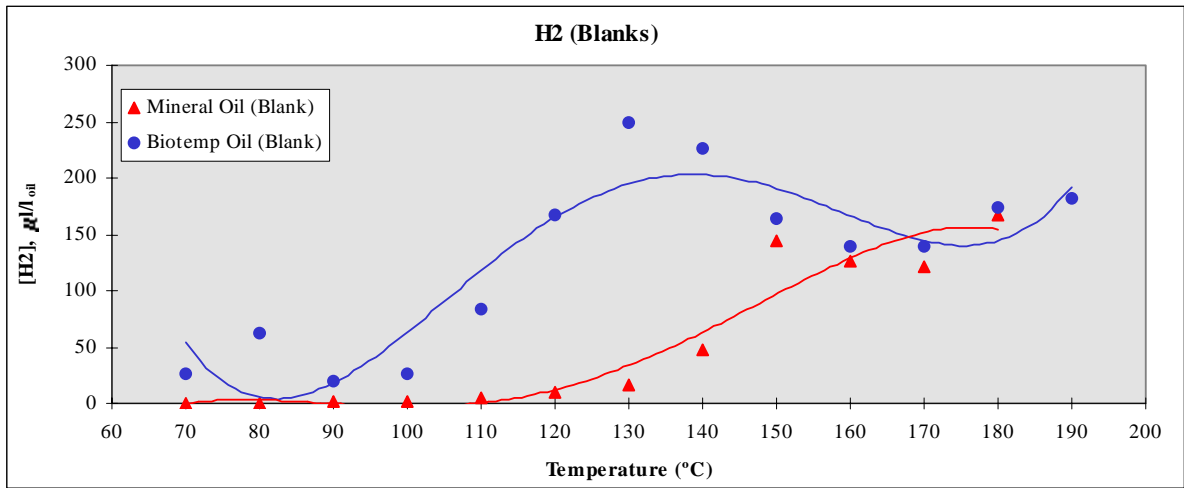
In the experiment made with BIOTEMP, the ratio paper/oil in weight was 400.

We present the results of both oils for each gas in the same graph to help the comparison of the DGA results in the two cases.

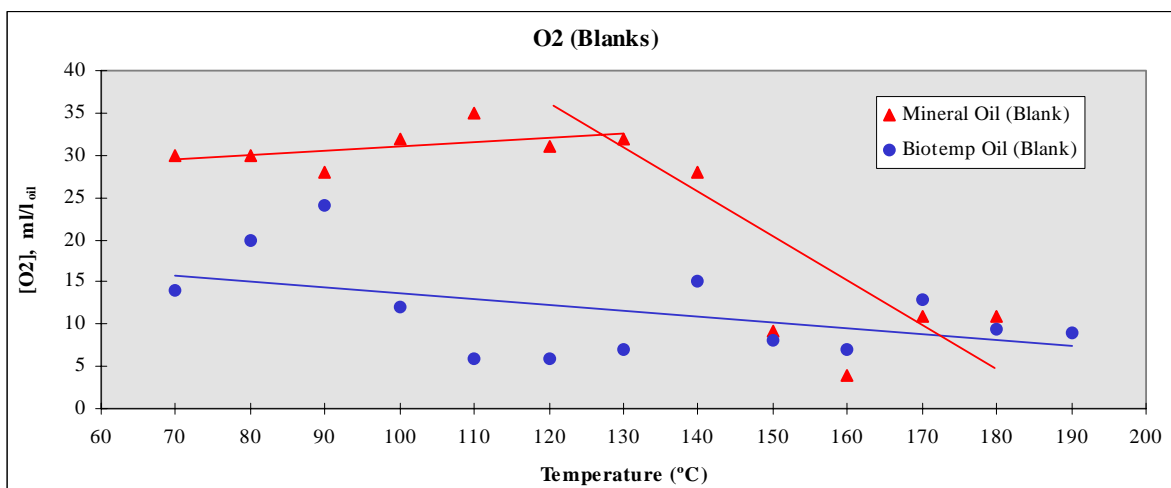
**DGA results** (determined by IEC 60567):

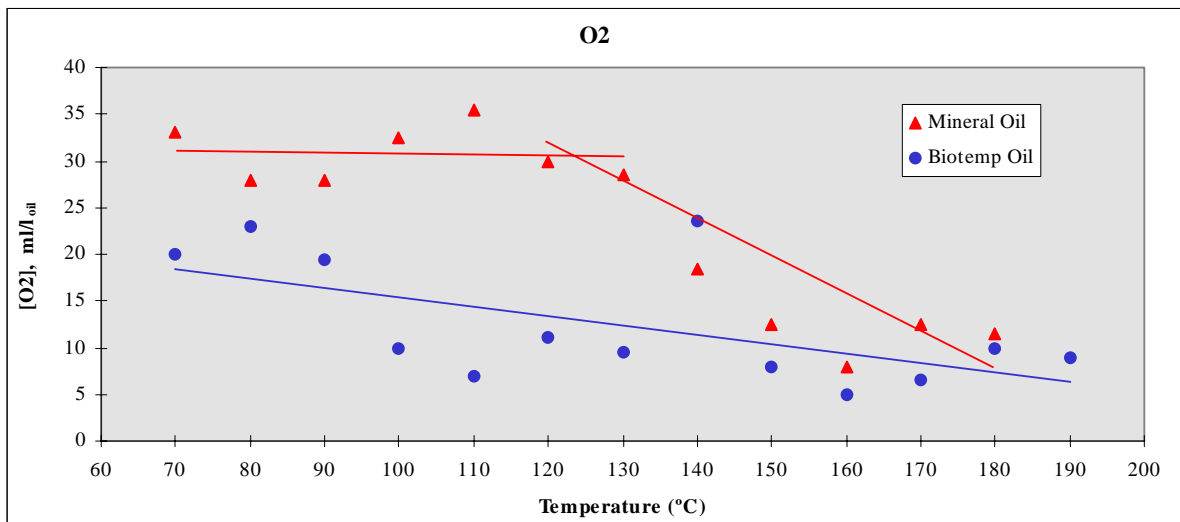
Temperature °C	Gas: H <sub>2</sub> , μlH <sub>2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	<4		<5	27		32
80	<4		15	63		16
90	<4 (1)		<4 (1)	19		39
100	<5 (2)		6	26		42
110	5		4	83		82
120	10		8	167		136
130	16		22	250		203
140	48		47	226		148
150	144		167	164		126
160	126		189	139		124
170	122		194	139		97
180	167		210	175		145
190	-		-	182		132

**Note:** - By “Mineral Oil” and “BIOTEMP Oil”, in this table and in the following tables, we mean the samples of these oils, which contain the pieces of copper wrapped with paper.

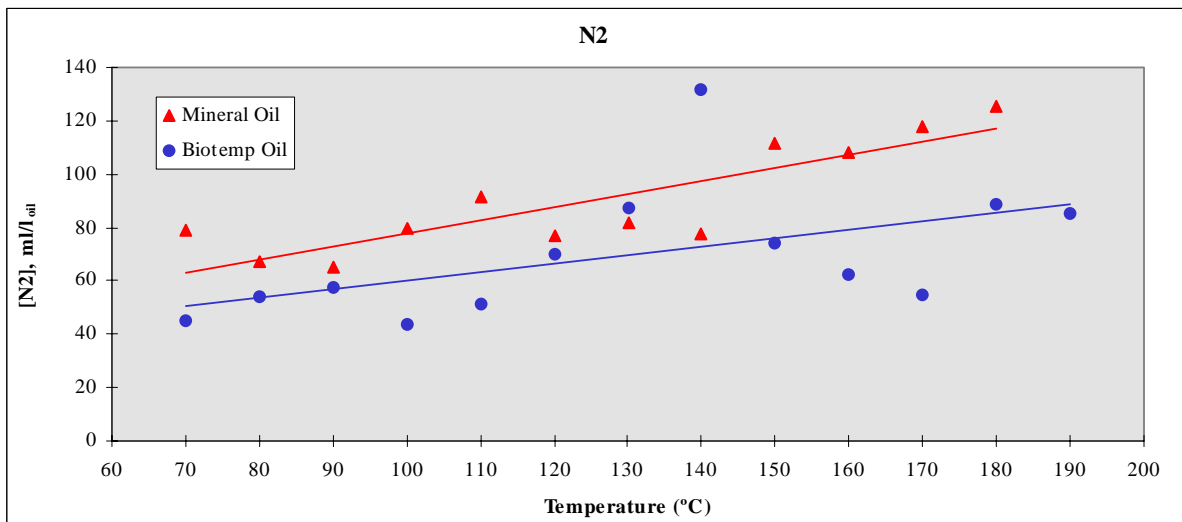
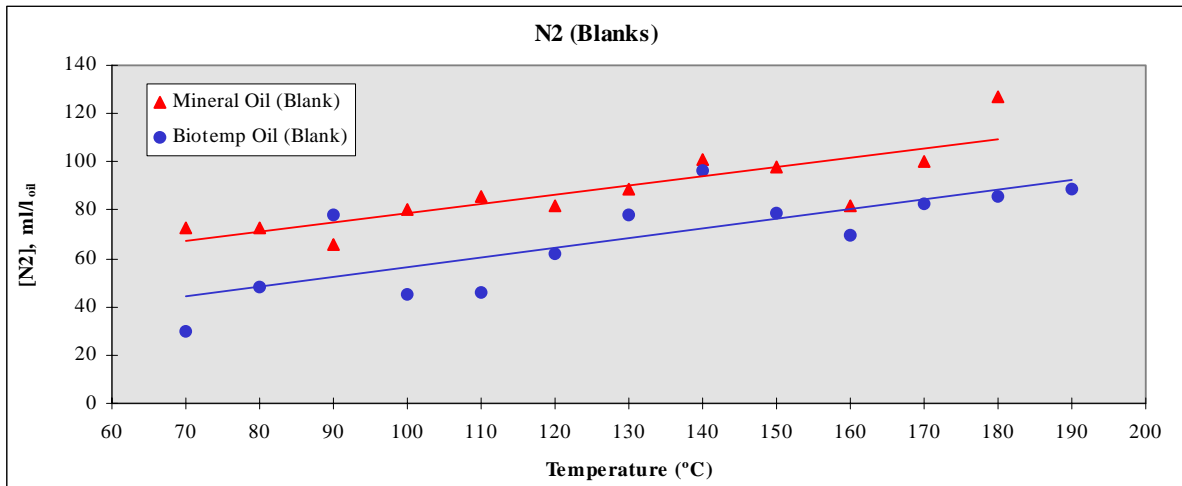


Temperature °C	Gas: O <sub>2</sub> , mlO <sub>2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	30		33	14		20
80	30		28	20		23
90	28		28	24		20
100	32		33	12		10
110	35		36	6		7
120	31		30	6		11
130	32		29	7		10
140	28		19	15		24
150	9		13	8		8
160	4		8	7		5
170	11		13	13		7
180	11		12	10		10
190	-		-	9		9

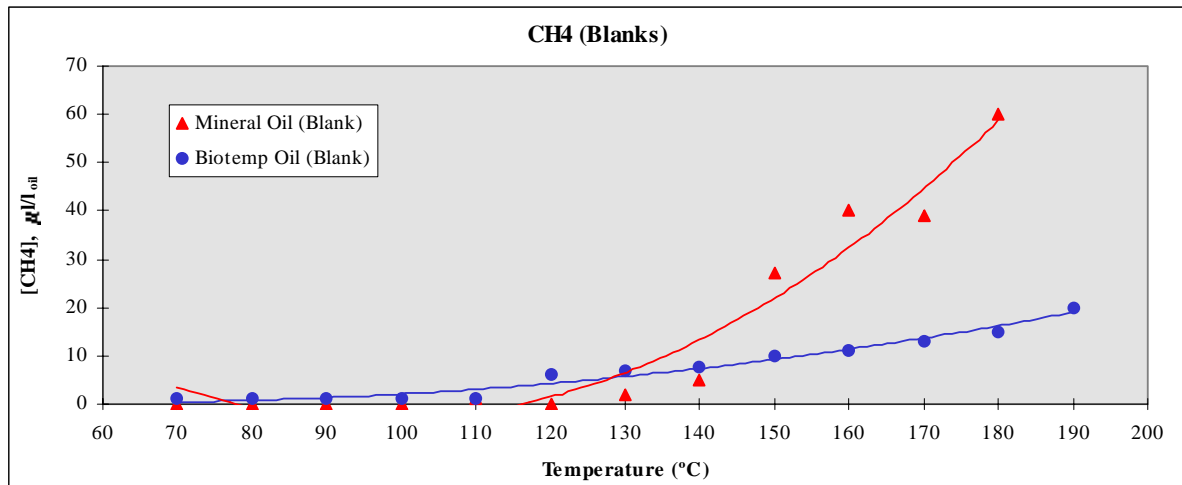


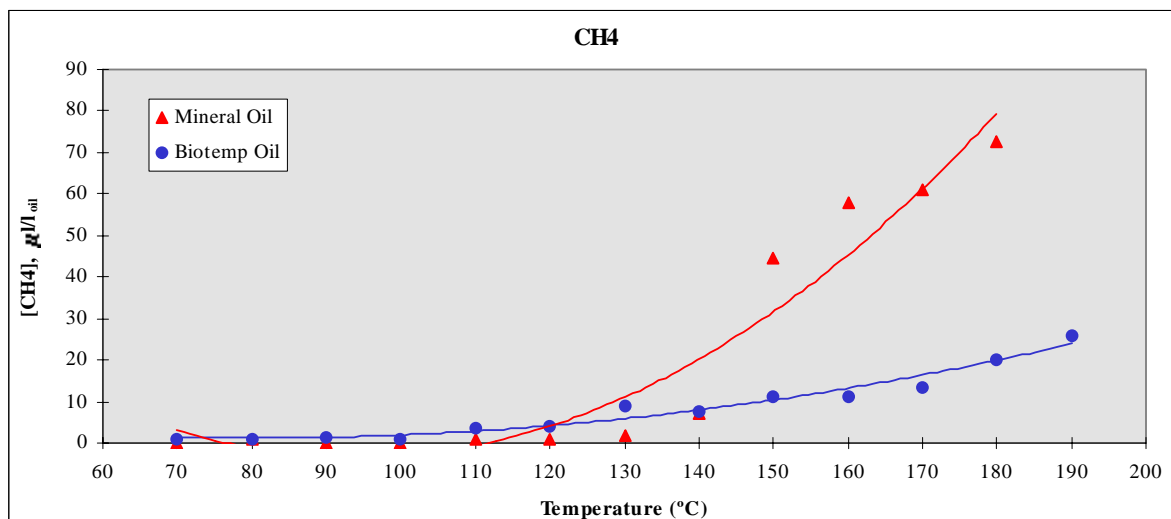


Temperature °C	Gas: N <sub>2</sub> , ml <sub>N<sub>2</sub></sub> /l <sub>oil</sub>				
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil
70	73		79	30	45
80	73		67	48	54
90	66		65	78	58
100	80		80	45	44
110	86		92	46	51
120	82		77	62	70
130	89		82	78	88
140	101		78	97	132
150	98		112	79	74
160	82		108	70	63
170	100		118	83	55
180	127		126	86	89
190	-		-	89	86

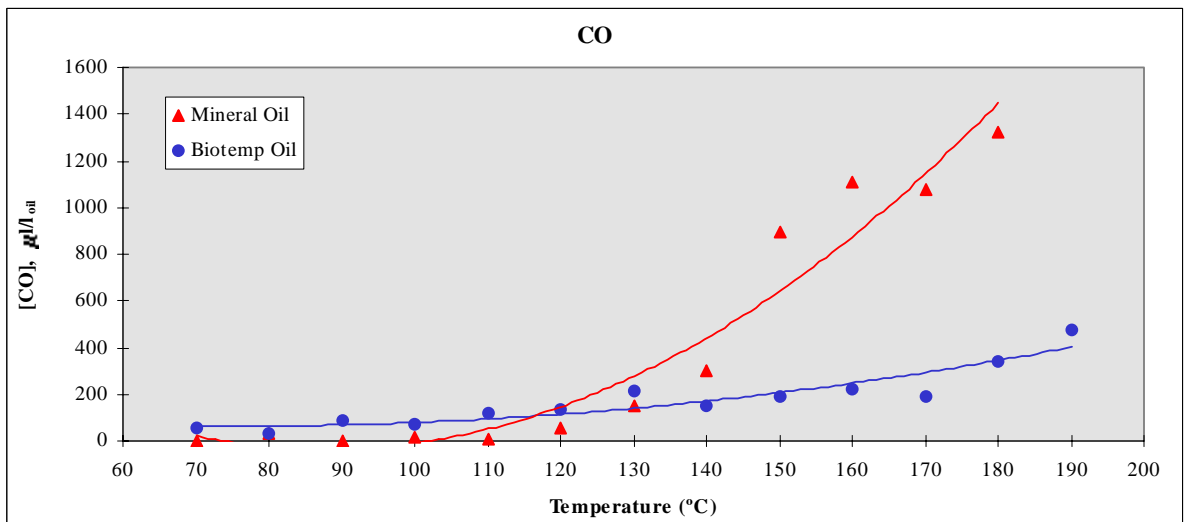
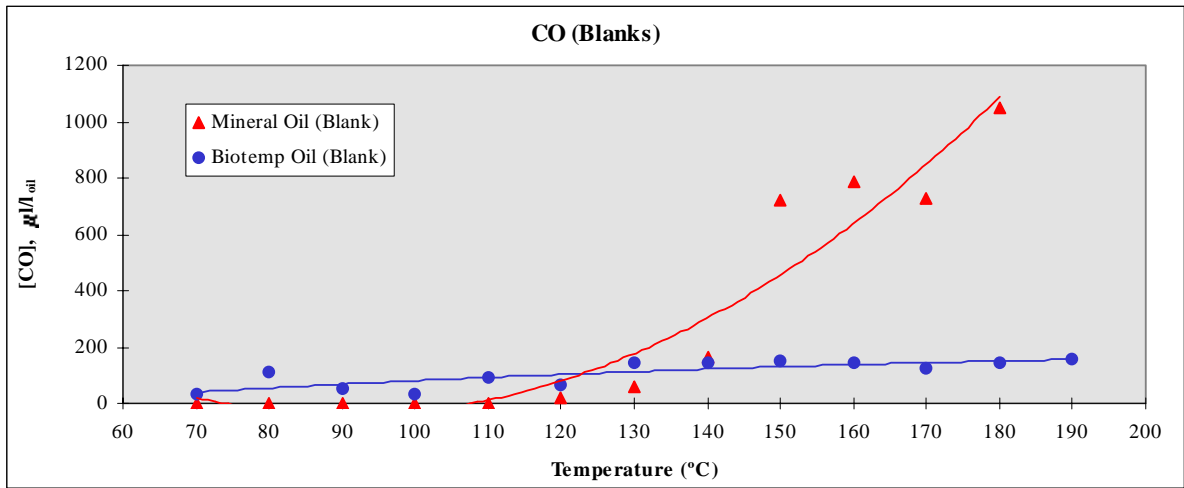


Temperature °C	Gas: CH <sub>4</sub> , μl <sub>CH4</sub> /l <sub>oil</sub>			
	Mineral (Blank)	Oil	Mineral Oil	Biotemp Oil
70	<1	<1	1	1
80	<1	1	1	1
90	<1	<1	<1	2
100	<1	<1	1	1
110	1	1	1	4
120	<1	1	6	4
130	2	2	7	9
140	5	7	8	8
150	27	45	10	11
160	40	58	11	11
170	39	61	13	14
180	60	73	15	20
190	-	-	20	26

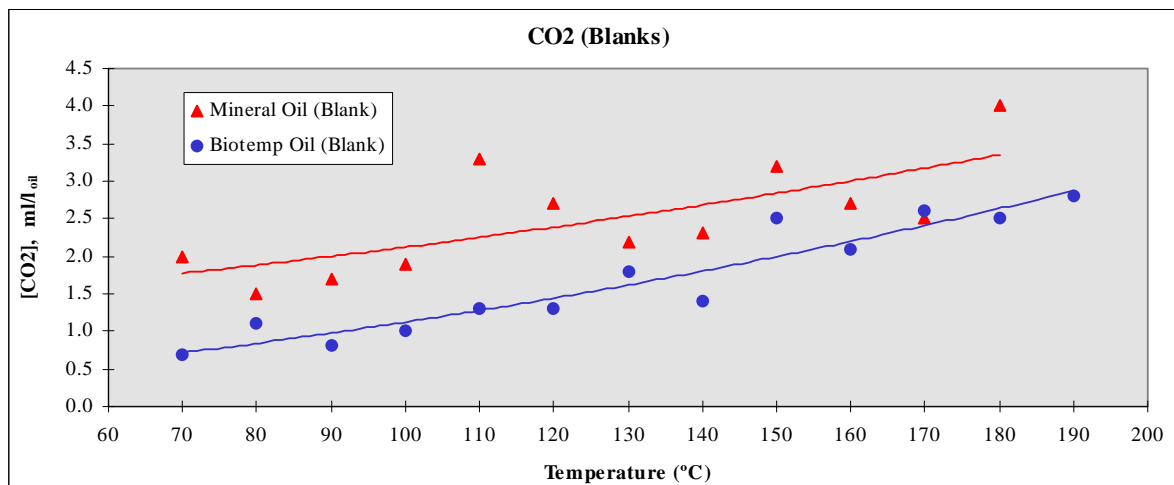


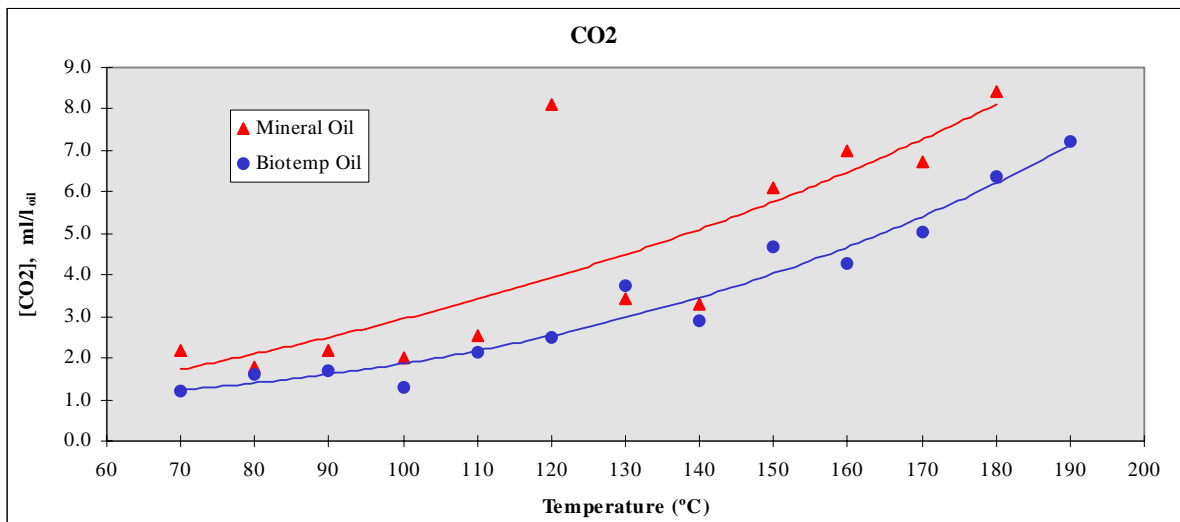


Temperature °C	Gas: CO, $\mu\text{CO}/\text{l}_{\text{oil}}$			
	Mineral (Blank)	Oil	Biotemp (Blank)	Oil
70	<28	<30	31	57
80	<28	35	111	28
90	<25	<25	<52	91
100	<30	<30	30	70
110	<33 (3)	10	92	117
120	<30 (19)	56	64	138
130	57	152	146	214
140	167	302	148	152
150	720	899	150	188
160	789	1107	147	224
170	726	1080	122	189
180	1048	1323	141	344
190	-	-	158	478

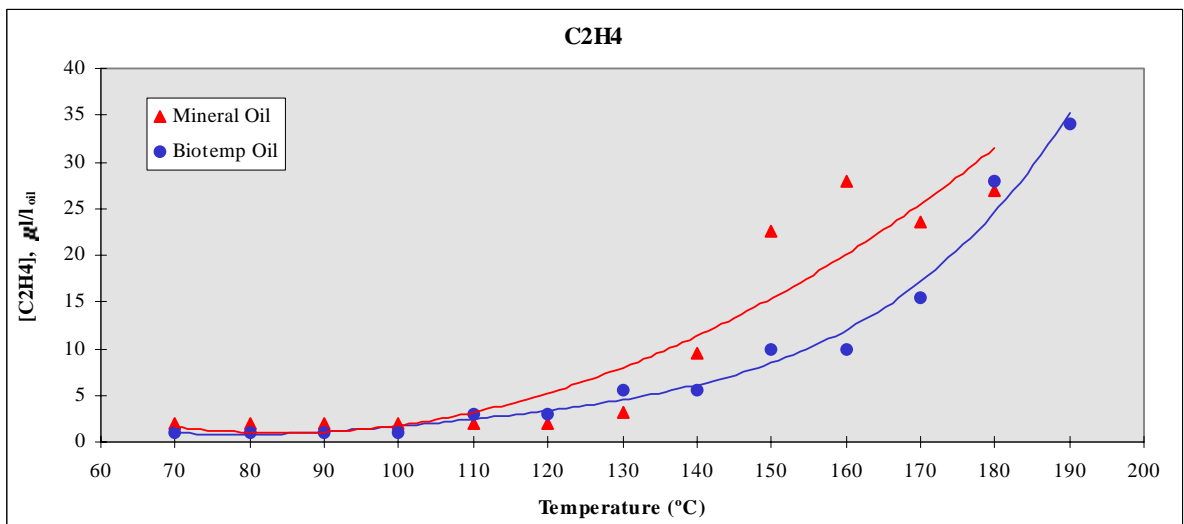
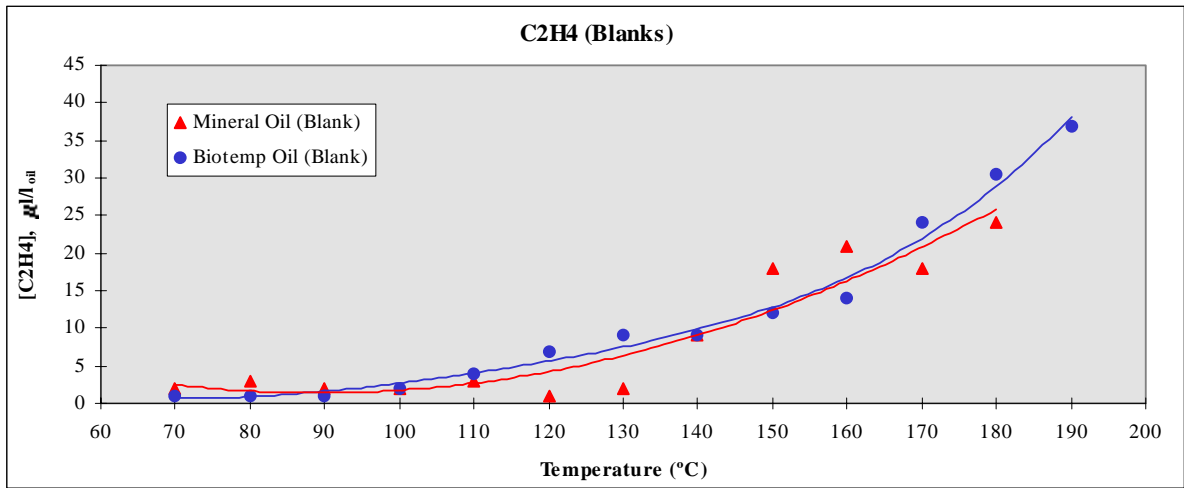


Temperature °C	Gas: CO <sub>2</sub> , ml <sub>CO2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	2.0		2.2	0.7		1.2
80	1.5		1.8	1.1		1.6
90	1.7		2.2	0.8		1.7
100	1.9		2.0	1.0		1.3
110	3.3		2.6	1.3		2.2
120	2.7		8.1	1.3		2.5
130	2.2		3.5	1.8		3.8
140	2.3		3.3	1.4		2.9
150	3.2		6.1	2.5		4.7
160	2.7		7.0	2.1		4.3
170	2.5		6.8	2.6		5.1
180	4.0		8.4	2.5		6.4
190	-		-	2.8		7.2

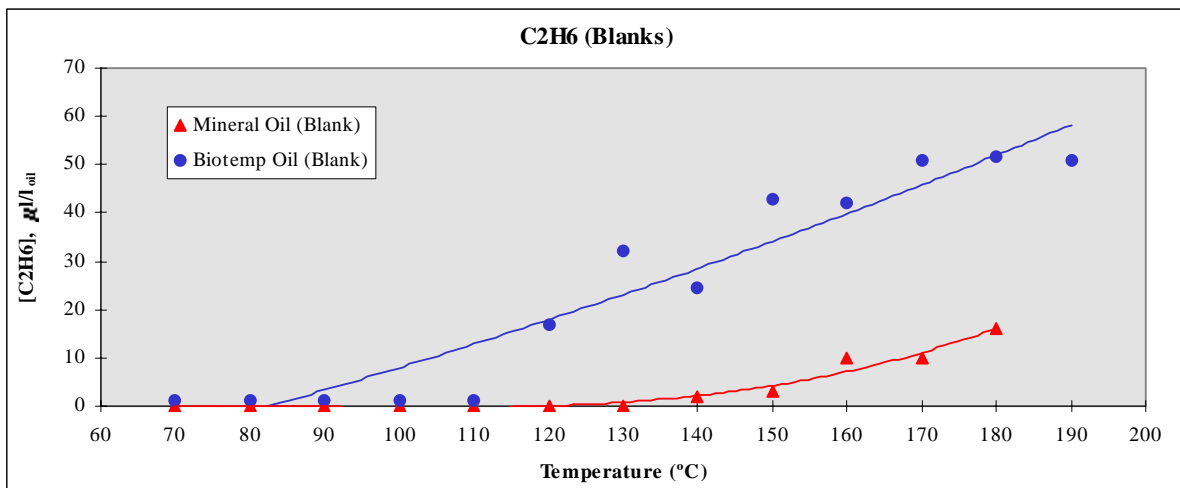


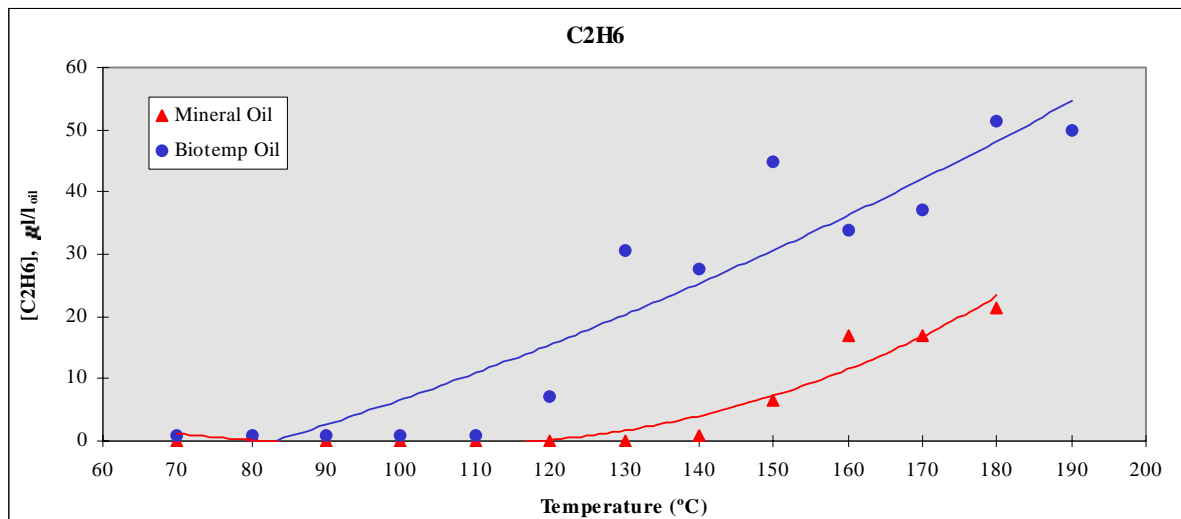


Temperature °C	Gas: C <sub>2</sub> H <sub>4</sub> , μl <sub>C<sub>2</sub>H<sub>4</sub></sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	2		2	1		1
80	3		2	1		1
90	2		2	1		1
100	2		2	2		1
110	3		2	4		3
120	1		2	7		3
130	2		3	9		6
140	9		10	9		6
150	18		23	12		10
160	21		28	14		10
170	18		24	24		16
180	24		27	31		28
190	-		-	37		34



Temperature °C	Gas: C <sub>2</sub> H <sub>6</sub> , μl <sub>C<sub>2</sub>H<sub>6</sub></sub> /l <sub>oil</sub>			
	Mineral (Blank)	Oil	Biotemp (Blank)	Oil
70	<1	<1	<1	<1
80	<1	1	<1	<1
90	<1	<1	<1	<1
100	<1	<1	<1	<1
110	<1	<1	<1	<1
120	<1	<1	17	7
130	<1	<1	32	31
140	2	1	25	28
150	3	7	43	45
160	10	17	42	34
170	10	17	51	37
180	16	22	52	51
190	-	-	51	50





**C<sub>2</sub>H<sub>2</sub>** – Not found for both oils at all temperatures.

## **CONCLUSION**

Concerning the DGA results of mineral insulating oil (in this case Nynas Nytro 11 EN with DBPC and BTA), we can conclude the following:

Generally, the concentrations of all gases increase, as the temperature increases.

**HYDROGEN** – Blank samples (oil without paper) and oil samples containing paper have produced the same quantity of hydrogen from 70 °C to about 150 °C, so we can conclude that for temperatures lower than 150°C, only the oil produces hydrogen.

Only at the temperature 150°C starts the production of hydrogen by thermal degradation of paper.

**OXYGEN** – The depletion of oxygen started at temperatures greater than 140°C, what means that the oxidation reaction starts being important, at this temperature.

**METHANE** – Not only the oil, but also the paper, can produce this gas at temperatures greater than 140°C.

**ETHANE** and **ETHYLENE** – Only small quantities of these gases were produced, not only by the oil, but also by the Kraft paper, at temperatures greater than 140°C.

**ACETYLENE** – No detectable quantity of acetylene was produced in this experiment, neither by the oil, nor by the paper, until the temperature of 180°C.

**CARBON MONOXIDE** and **CARBON DIOXIDE** – The main source of the production of these gases is the thermal degradation of Kraft paper, for temperatures greater than 130°C. Although the oil also produces those gases, they are produced in minor quantity, in comparison with the same gases produced by the paper.

We have **repeated the same experiment using a vegetable insulating oil (BIOTEMP)** instead of a mineral oil.

In the case of **BIOTEMP oil**, as in the case of mineral oil, **the production of all gases (hydrogen, carbon oxides and, hydrocarbons) increases as the temperature rises.**

However, **for each gas (exception made of ethane) the concentration of gas in BIOTEMP oil, at each temperature, is lower than the concentration of the same gas at the same temperature, in mineral insulating oil.**

**In the case of ethane, its production starts, in BIOTEMP oil, at a lower temperature (120°C) that in the mineral oil.**

**Also the concentration of ethane produced in BIOTEMP oil is several times higher than the concentration of ethane produced in mineral insulating oil at the same temperature throughout the whole range of studied temperatures.**

**So, this experiment shows the influence of the type and quality of oil and also the oil temperature (that is to say, the operating conditions including the transformer loading or load profile and also the ambient temperature) in the rate of gas production in transformers.**

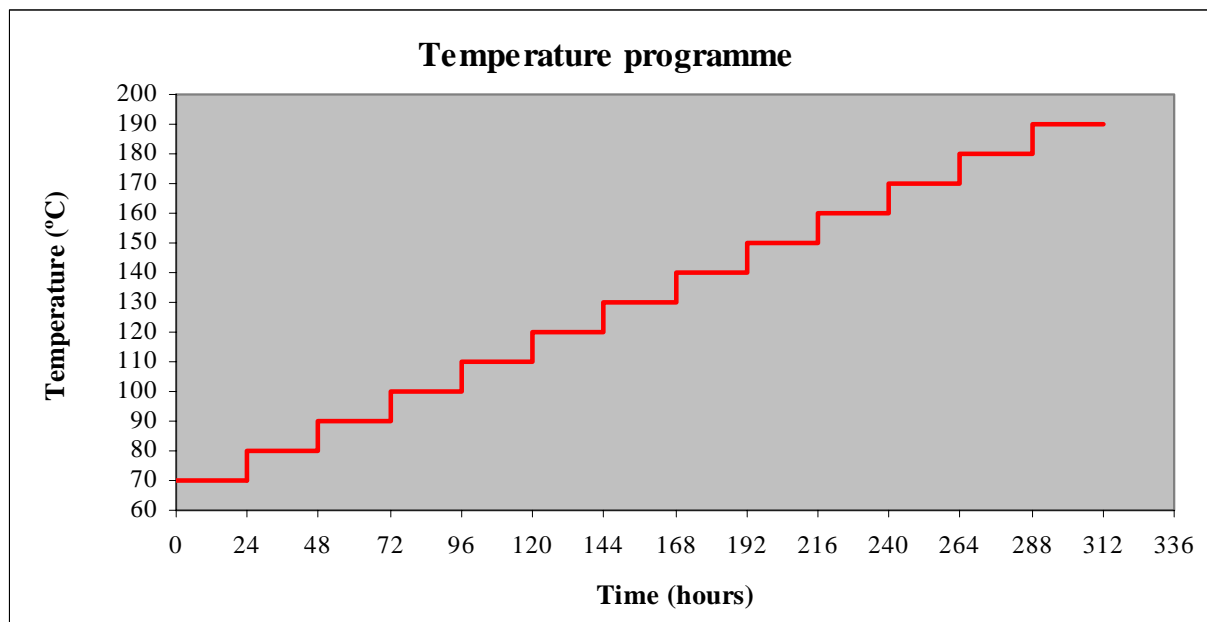
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**Annex I**

**Experimental study on the thermal degradation of insulating oil / Kraft paper by DGA**

**Temperature programme**

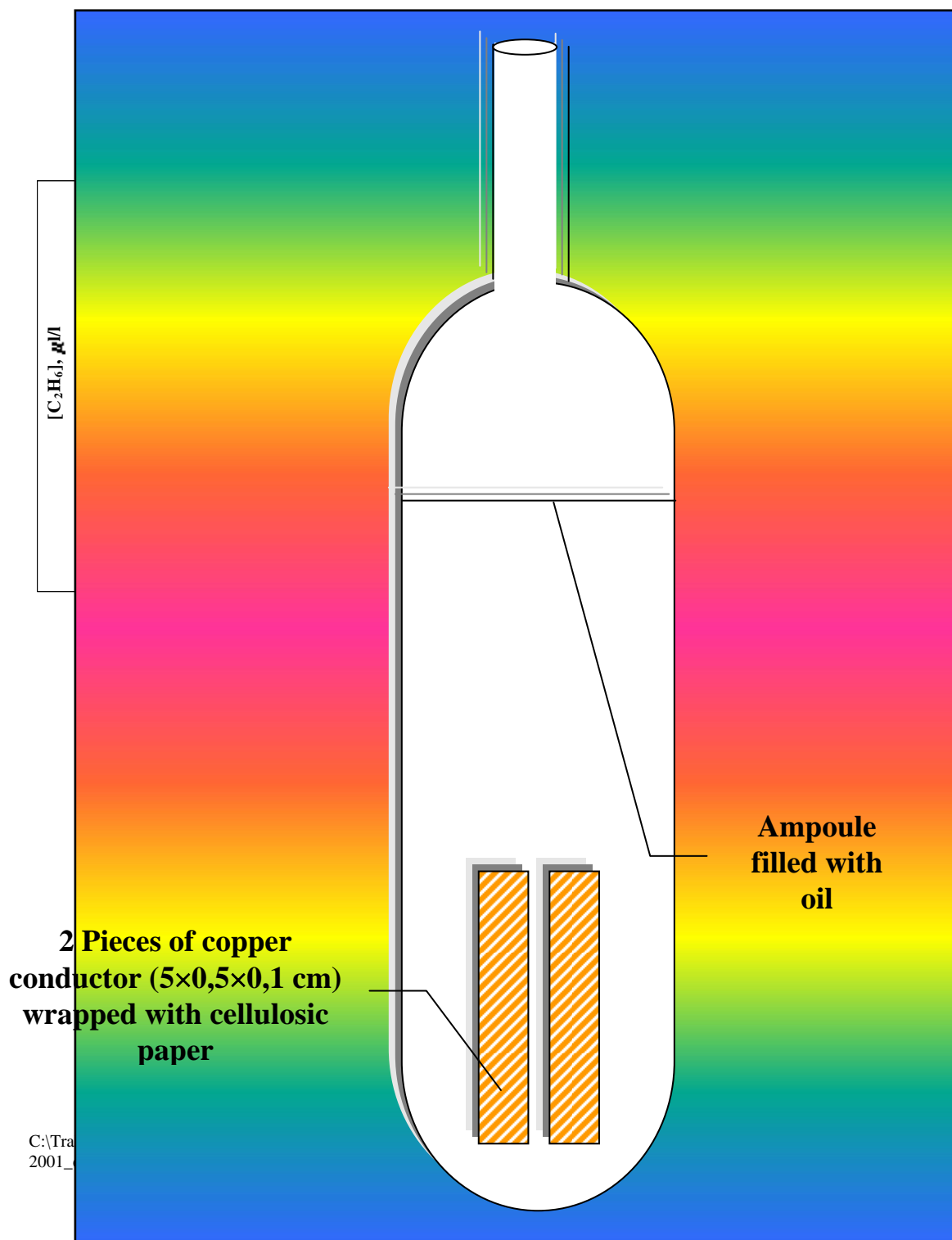


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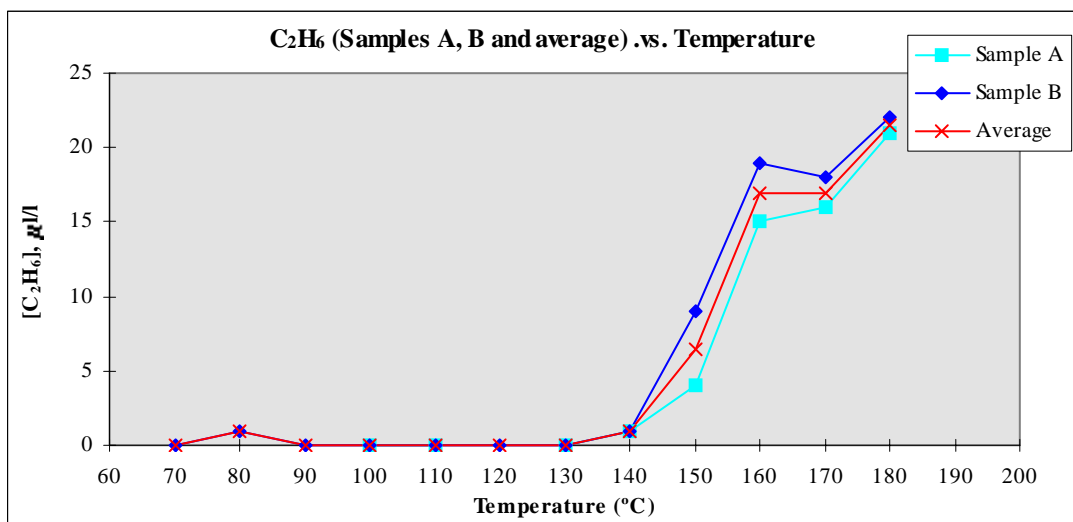
**Annex II**

**Experimental study on the thermal degradation of insulating oil / Kraft paper by DGA**



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**C<sub>2</sub>H<sub>2</sub>** – Not found for both oils at all temperatures.

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**Part 2 – Vegetable insulating oil (Oil BIOTEMP) vs mineral insulating oil (Oil Nynas Nytro 11 EN)**

We also repeated this experiment using a vegetable insulating oil, instead of a mineral oil (in this case the BIOTEMP oil), and have obtained the following DGA results.

In the experiment made with BIOTEMP, the ratio paper/oil in weight was 400.

We present the results of both oils for each gas in the same graph to help the comparison of the DGA results in the two cases.

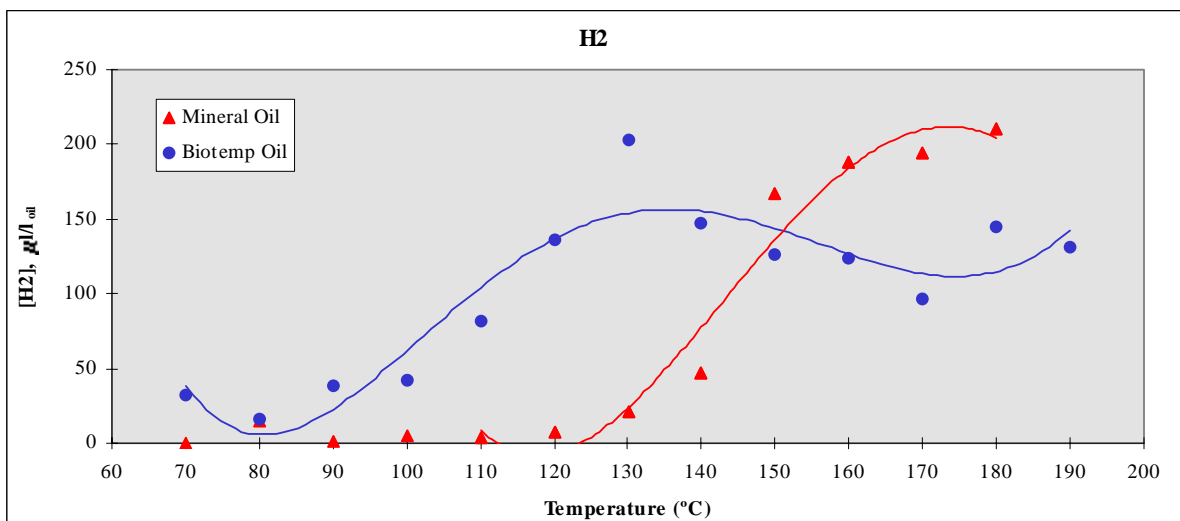
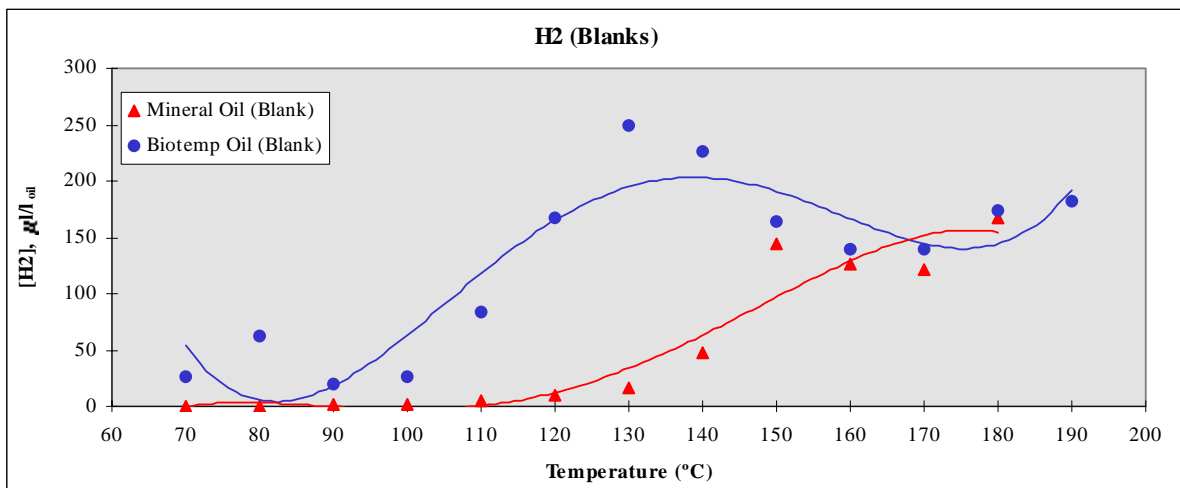
**DGA results** (determined by IEC 60567):

Temperature °C	Gas: H <sub>2</sub> , μl <sub>H2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	<4		<5	27		32
80	<4		15	63		16
90	<4 (1)		<4 (1)	19		39
100	<5 (2)		6	26		42
110	5		4	83		82
120	10		8	167		136
130	16		22	250		203
140	48		47	226		148
150	144		167	164		126
160	126		189	139		124
170	122		194	139		97
180	167		210	175		145
190	-		-	182		132

**Note:** - By “Mineral Oil” and “BIOTEMP Oil”, in this table and in the following tables, we mean the samples of these oils, which contain the pieces of copper wrapped with paper.

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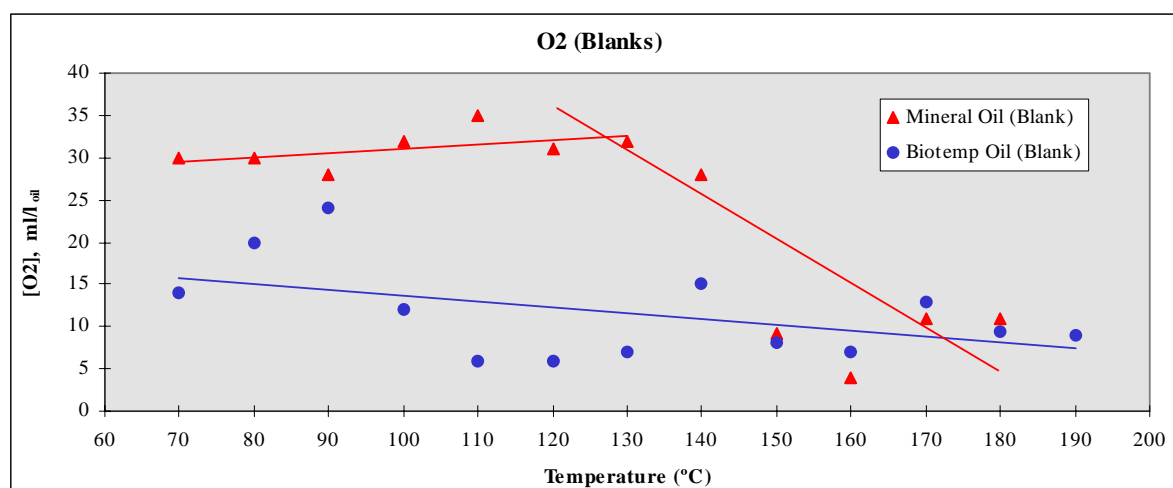
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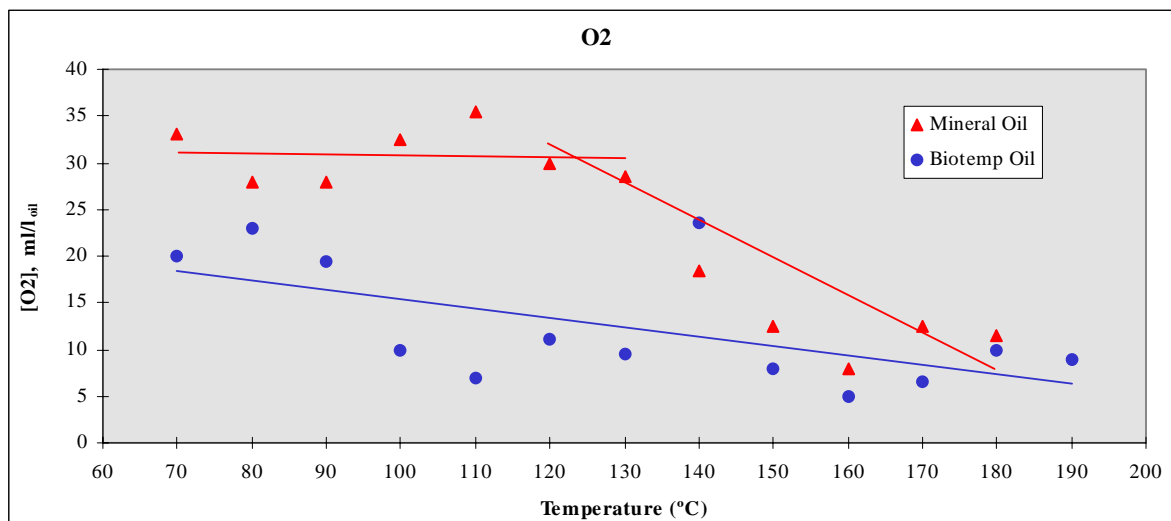
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Temperature °C	Gas: O <sub>2</sub> , mlO <sub>2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	30		33	14		20
80	30		28	20		23
90	28		28	24		20
100	32		33	12		10
110	35		36	6		7
120	31		30	6		11
130	32		29	7		10
140	28		19	15		24
150	9		13	8		8
160	4		8	7		5
170	11		13	13		7
180	11		12	10		10
190	-		-	9		9



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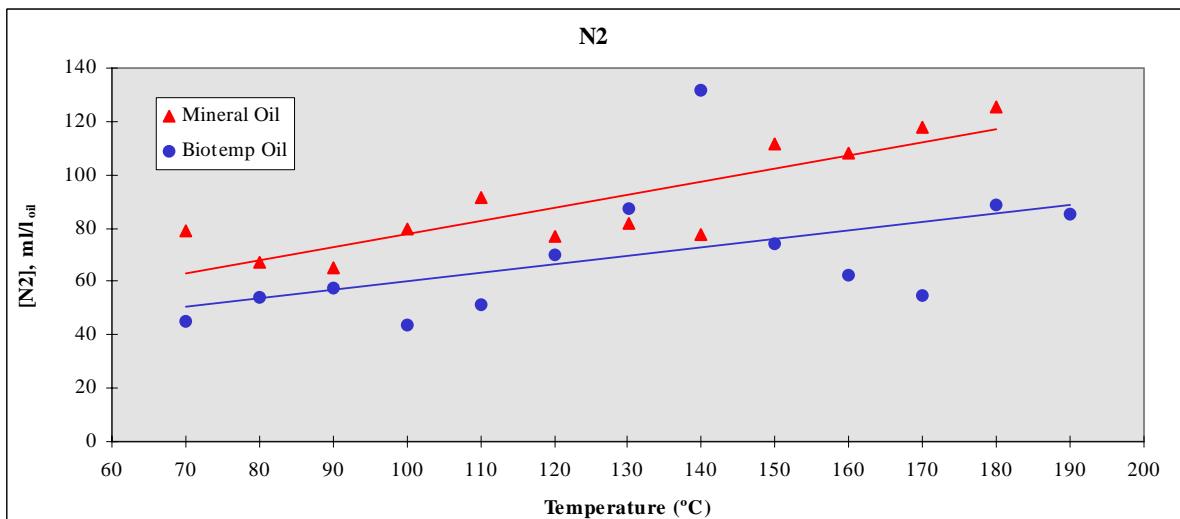
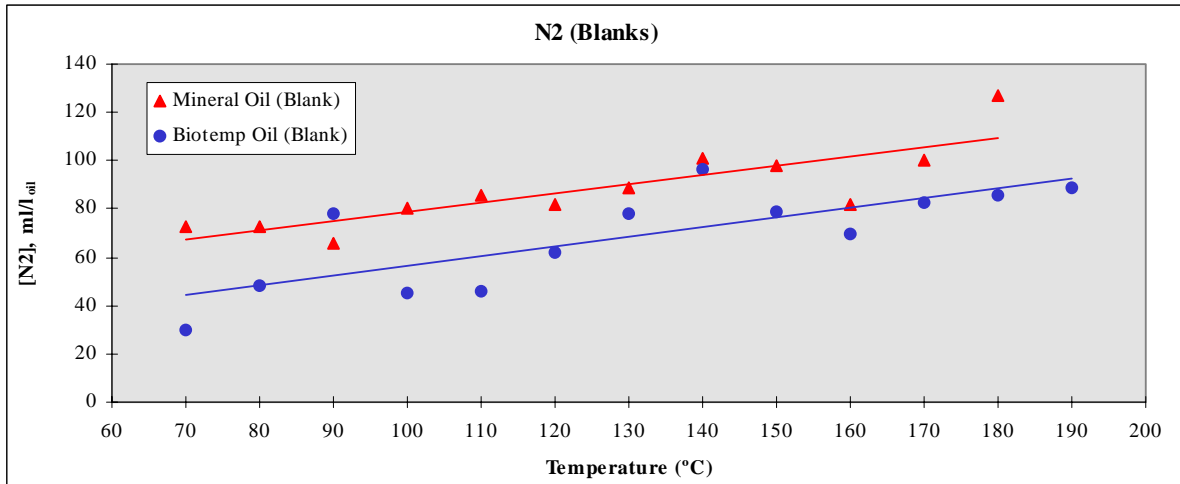
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Temperature °C	Gas: N <sub>2</sub> , ml <sub>N<sub>2</sub></sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	73		79	30		45
80	73		67	48		54
90	66		65	78		58
100	80		80	45		44
110	86		92	46		51
120	82		77	62		70
130	89		82	78		88
140	101		78	97		132
150	98		112	79		74
160	82		108	70		63
170	100		118	83		55
180	127		126	86		89
190	-		-	89		86

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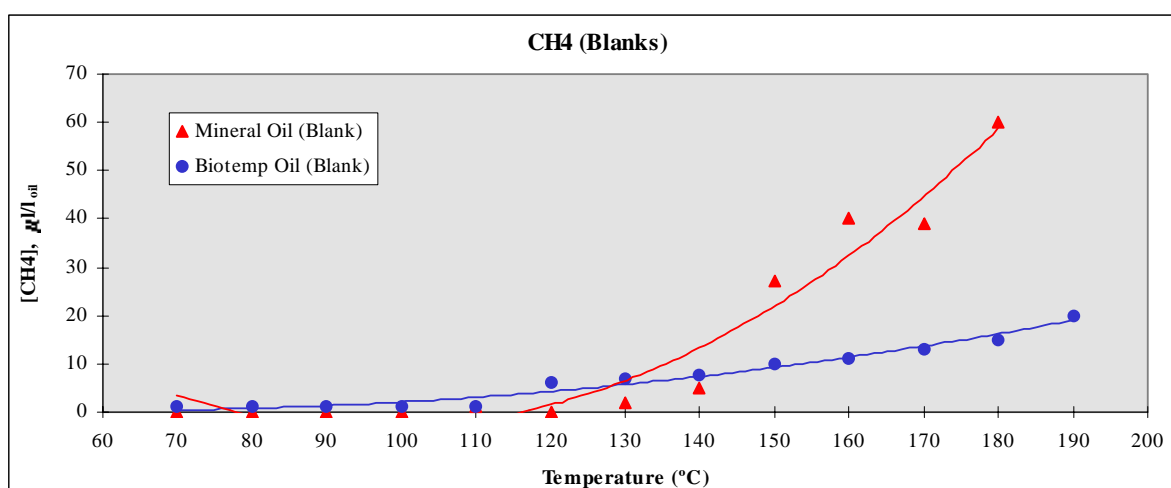
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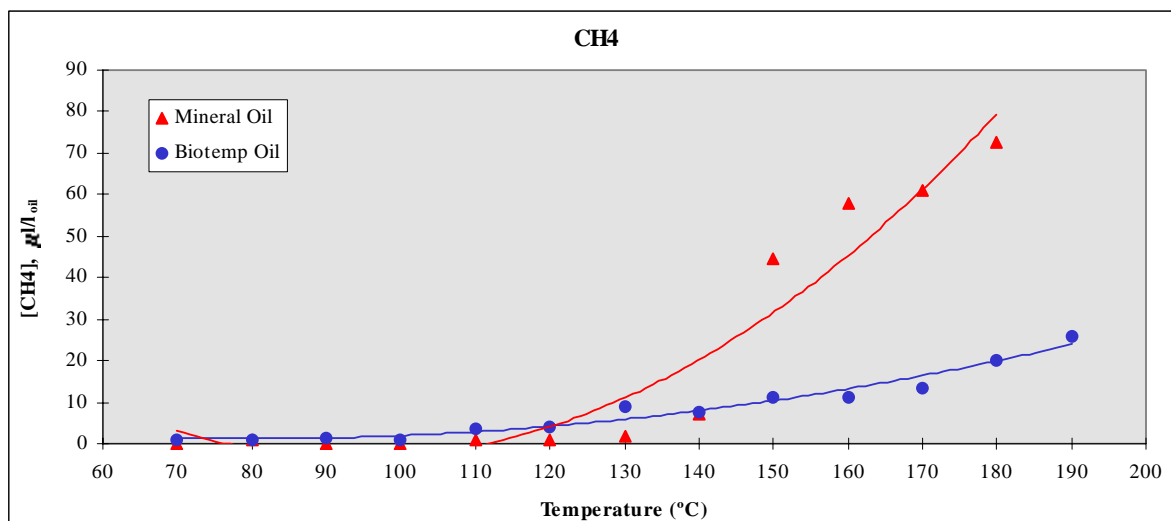
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Temperature °C	Gas: CH <sub>4</sub> , μl <sub>CH<sub>4</sub></sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	<1	<1	<1	1	1	1
80	<1	<1	1	1	1	1
90	<1	<1	<1	<1	<1	2
100	<1	<1	<1	1	1	1
110	1	1	1	1	1	4
120	<1	<1	1	6	6	4
130	2	2	2	7	7	9
140	5	5	7	8	8	8
150	27	27	45	10	10	11
160	40	40	58	11	11	11
170	39	39	61	13	13	14
180	60	60	73	15	15	20
190	-	-	-	20	20	26



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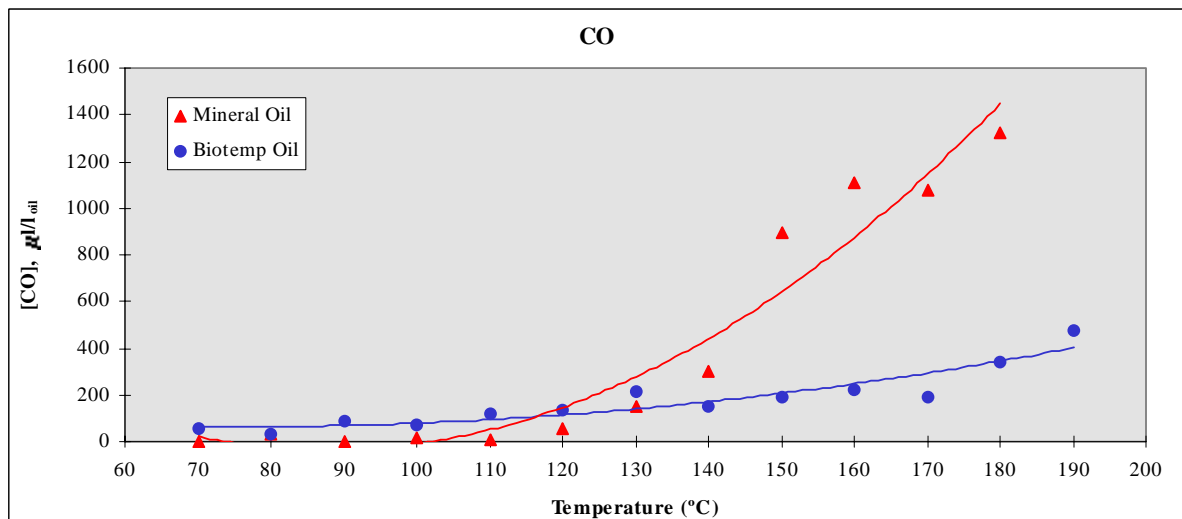
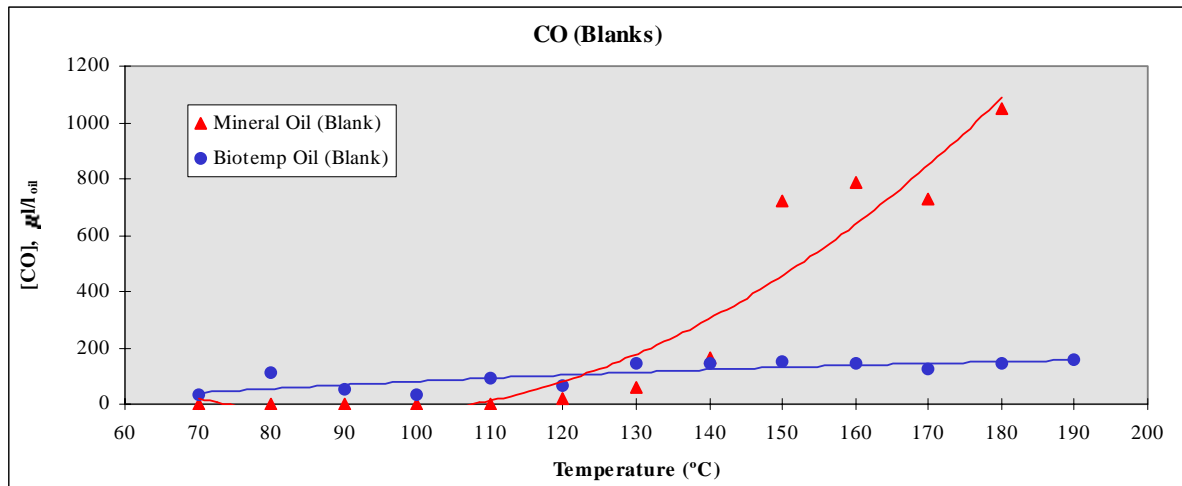
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Temperature °C	Gas: CO, µl <sub>CO</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	<28		<30	31		57
80	<28		35	111		28
90	<25		<25	<52		91
100	<30		<30	30		70
110	<33 (3)		10	92		117
120	<30 (19)		56	64		138
130	57		152	146		214
140	167		302	148		152
150	720		899	150		188
160	789		1107	147		224
170	726		1080	122		189
180	1048		1323	141		344
190	-		-	158		478

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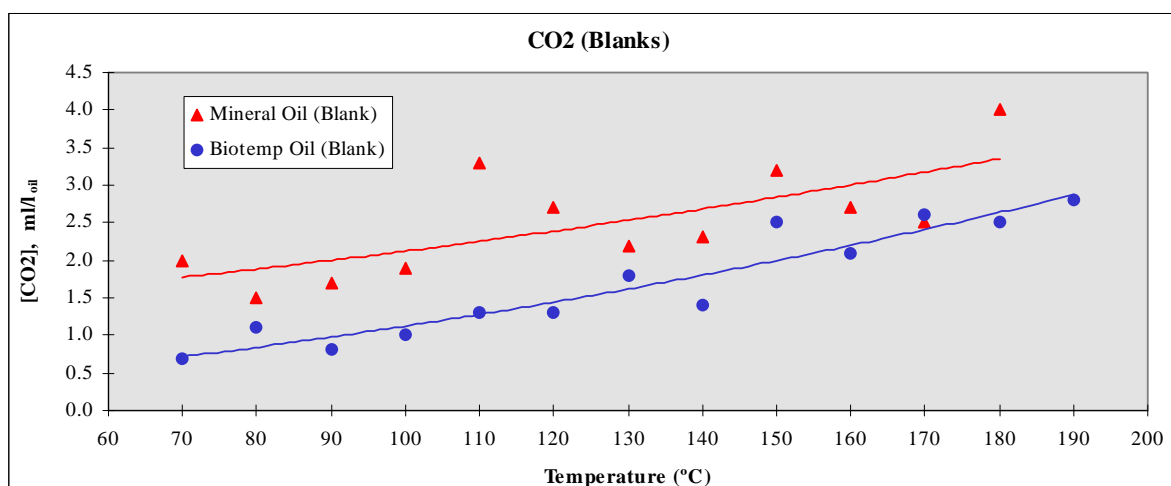
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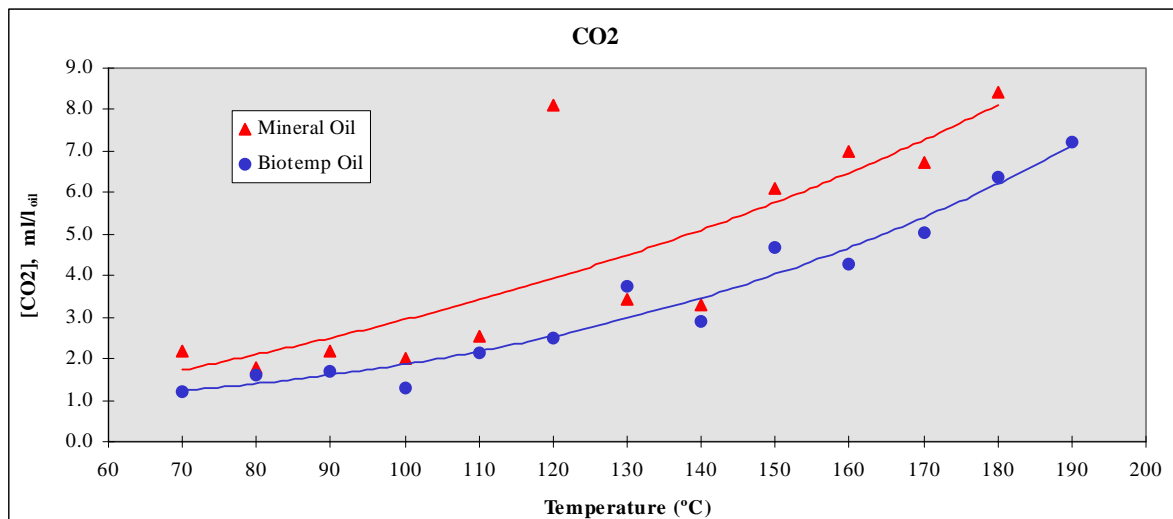
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Temperature °C	Gas: CO <sub>2</sub> , ml <sub>CO2</sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	2.0		2.2	0.7		1.2
80	1.5		1.8	1.1		1.6
90	1.7		2.2	0.8		1.7
100	1.9		2.0	1.0		1.3
110	3.3		2.6	1.3		2.2
120	2.7		8.1	1.3		2.5
130	2.2		3.5	1.8		3.8
140	2.3		3.3	1.4		2.9
150	3.2		6.1	2.5		4.7
160	2.7		7.0	2.1		4.3
170	2.5		6.8	2.6		5.1
180	4.0		8.4	2.5		6.4
190	-		-	2.8		7.2



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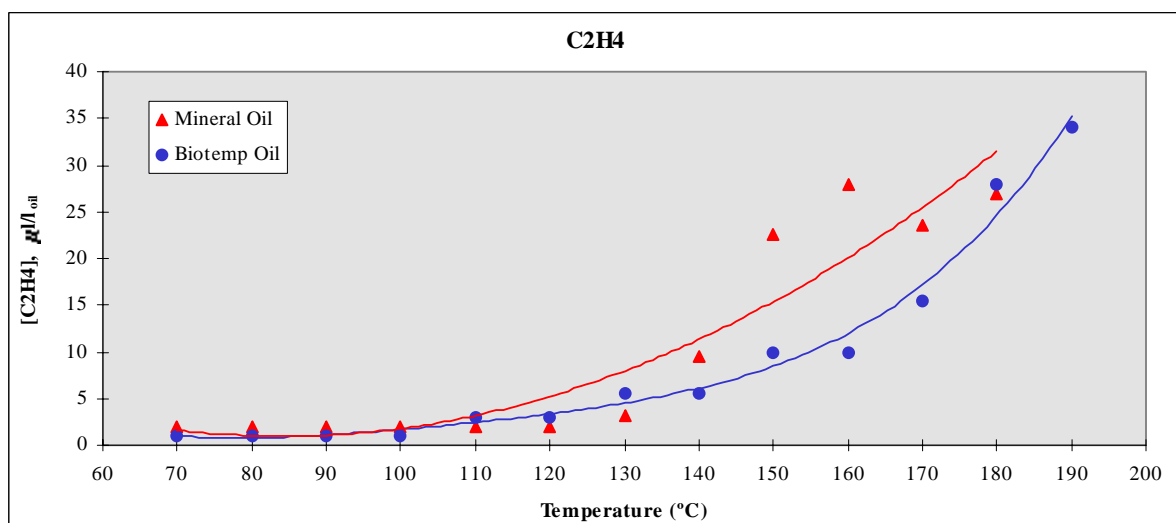
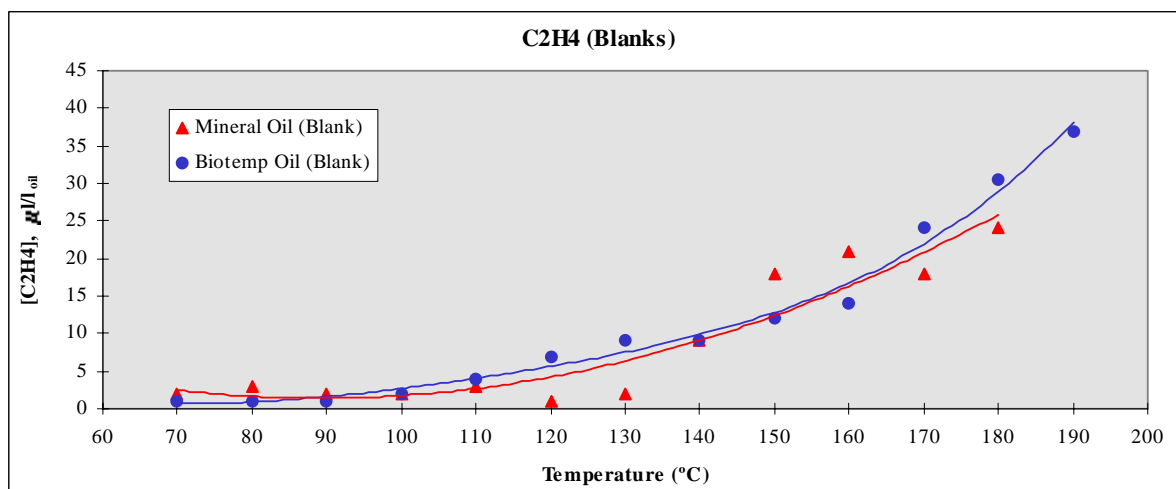
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Temperature °C	Gas: C <sub>2</sub> H <sub>4</sub> , μl <sub>C<sub>2</sub>H<sub>4</sub></sub> /l <sub>oil</sub>					
	Mineral (Blank)	Oil	Mineral Oil	Biotemp (Blank)	Oil	Biotemp Oil
70	2		2	1		1
80	3		2	1		1
90	2		2	1		1
100	2		2	2		1
110	3		2	4		3
120	1		2	7		3
130	2		3	9		6
140	9		10	9		6
150	18		23	12		10
160	21		28	14		10
170	18		24	24		16
180	24		27	31		28
190	-		-	37		34

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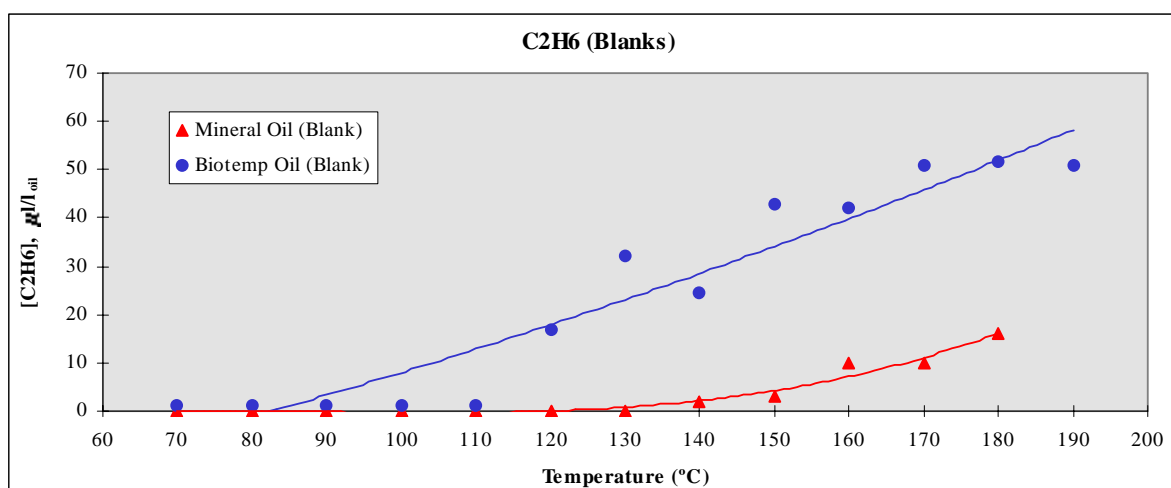
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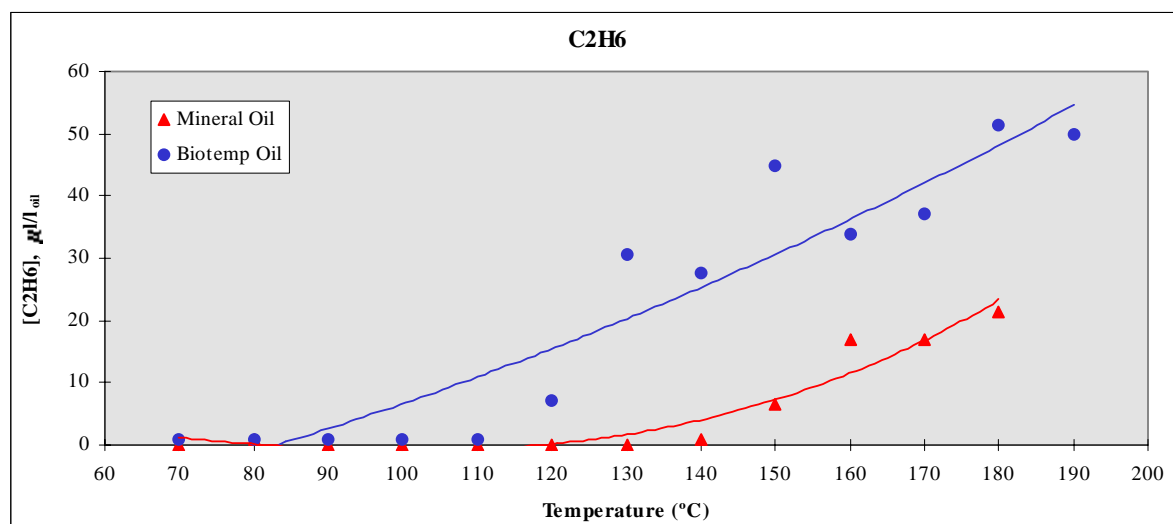
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Temperature °C	Gas: C <sub>2</sub> H <sub>6</sub> , μl <sub>C<sub>2</sub>H<sub>6</sub></sub> /l <sub>oil</sub>			
	Mineral (Blank)	Oil	Biotemp (Blank)	Oil
70	<1	<1	<1	<1
80	<1	1	<1	<1
90	<1	<1	<1	<1
100	<1	<1	<1	<1
110	<1	<1	<1	<1
120	<1	<1	17	7
130	<1	<1	32	31
140	2	1	25	28
150	3	7	43	45
160	10	17	42	34
170	10	17	51	37
180	16	22	52	51
190	-	-	51	50



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**C<sub>2</sub>H<sub>2</sub>** – Not found for both oils at all temperatures.

## **CONCLUSION**

Concerning the DGA results of mineral insulating oil (in this case Nynas Nytro 11 EN with DBPC and BTA), we can conclude the following:

Generally, the concentrations of all gases increase, as the temperature increases.

**HYDROGEN** – Blank samples (oil without paper) and oil samples containing paper have produced the same quantity of hydrogen from 70 °C to about 150 °C, so we can conclude that for temperatures lower than 150°C, only the oil produces hydrogen.

Only at the temperature 150°C starts the production of hydrogen by thermal degradation of paper.

**OXYGEN** – The depletion of oxygen started at temperatures greater than 140°C, what means that the oxidation reaction starts being important, at this temperature.

**METHANE** – Not only the oil, but also the paper, can produce this gas at temperatures greater than 140°C.

**ETHANE and ETHYLENE** – Only small quantities of these gases were produced, not only by the oil, but also by the Kraft paper, at temperatures greater than 140°C.

**ACETYLENE** – No detectable quantity of acetylene was produced in this experiment, neither by the oil, nor by the paper, until the temperature of 180°C.

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**CARBON MONOXIDE** and **CARBON DIOXIDE** – The main source of the production of these gases is the thermal degradation of Kraft paper, for temperatures greater than 130°C. Although the oil also produces those gases, they are produced in minor quantity, in comparison with the same gases produced by the paper.

We have **repeated the same experiment using a vegetable insulating oil (BIOTEMP)** instead of a mineral oil.

In the case of **BIOTEMP oil**, as in the case of mineral oil, **the production of all gases (hydrogen, carbon oxides and, hydrocarbons) increases as the temperature rises.**

However, **for each gas (exception made of ethane) the concentration of gas in BIOTEMP oil, at each temperature, is lower than the concentration of the same gas at the same temperature, in mineral insulating oil.**

**In the case of ethane, its production starts, in BIOTEMP oil, at a lower temperature (120°C) than in the mineral oil.**

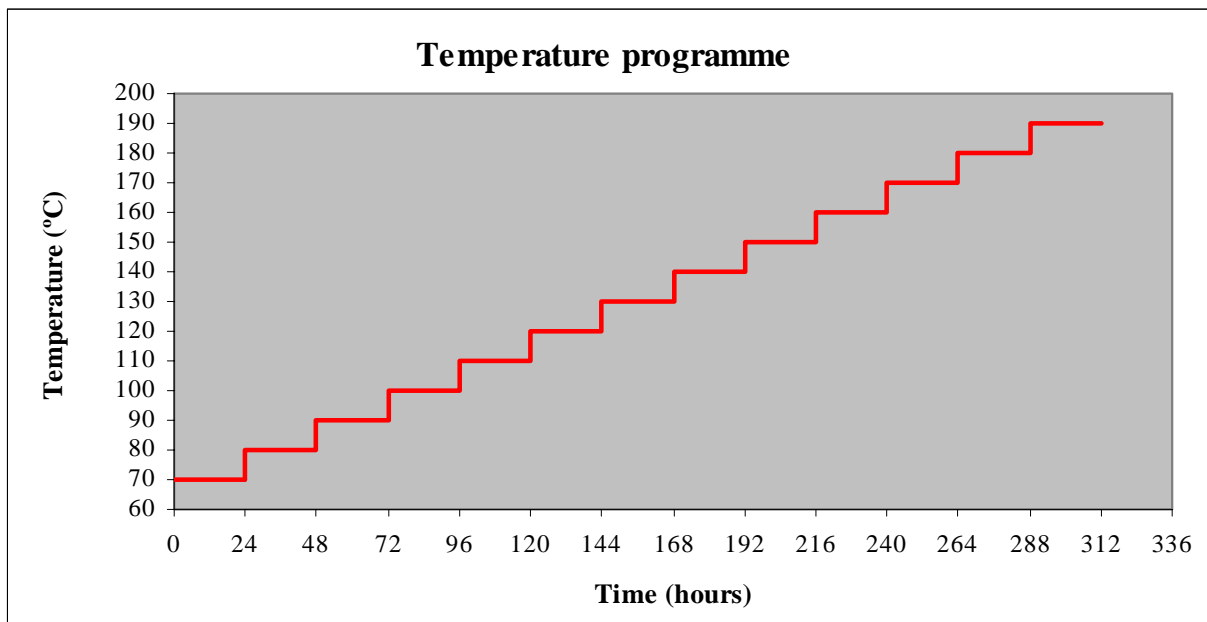
**Also the concentration of ethane produced in BIOTEMP oil is several times higher than the concentration of ethane produced in mineral insulating oil at the same temperature throughout the whole range of studied temperatures.**

**So, this experiment shows the influence of the type and quality of oil and also the oil temperature (that is to say, the operating conditions including the transformer loading or load profile and also the ambient temperature) in the rate of gas production in transformers.**

## Annex I

### Experimental study on the thermal degradation of insulating oil / Kraft paper by DGA

#### Temperature programme



## Annex II

### Experimental study on the thermal degradation of insulating oil / Kraft paper by DGA

