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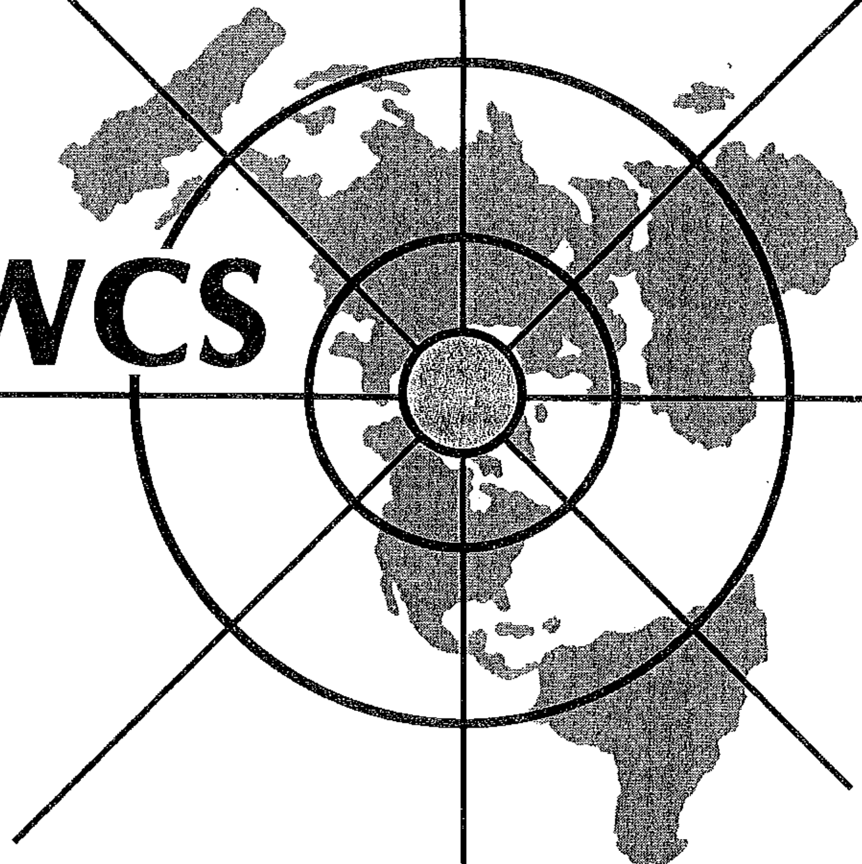

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Fire Parameters and Combustion Properties of Cable Pulling Compound Residues

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FIRE PARAMETERS AND COMBUSTION PROPERTIES OF CABLE PULLING COMPOUND RESIDUES

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SUMMARY

Fire parameters of cable lubricant residues have been determined using a specially designed device. The device simulates field conditions by heating lubricant contained in a conduit. The heating rate (heat flux) can be varied to develop various fire parameters.

Significant combustion differences are found among commercially available lubricants. These differences include: critical heat flux, ignition energies, ignition temperature, time of burn and tendency to spread (propagate) or extinguish fire.

The most combustible of residues are from lubricants based on Hydrocarbon Waxes or combination Wax/Soaps. These residues have critical heat fluxes well under 40 KW/m^2, ignition energy of 15,000-20,000 KJ/m^2 and ignition temperatures of 230°-330°C. They burn vigorously for lengthy periods (5-15 minutes) and spread flame along a conduit whether or not the combustion is supported by an outside heat source.

Certain Polymer, Polymer/Teflon and Bentonite/Glycol Lubricants show higher ignition energies and shorter burn times than the Wax-based materials. However, these lubricants still sustain and spread flame once ignited.

One lubricant, a High-performance Gel Polymer, was found to be considerably less combustible than fire-retardant cables. In the High-performance Gel Polymer, ignition was very difficult to induce, burn times were nil and flame spread did not occur.

INTRODUCTION

Cable pulling compunds are specialty lubricants which lower the force or tension on a cable as it is pulled into conduit. As field installers know, the use of such lubricants can often mean the difference between a successfully installed cable or one damaged by excessive mechanical stress.

Cable lubricants reduce pulling tension by reducing the frictional force between the cable jacket and the conduit wall. Low cable lubricant coefficient of friction is an important characteristic, and has been the subject of much study and measurement.

A second factor considered when choosing a cable pulling lubricant is its compatibility with the cable jacket. The lubricant should not affect the jacket's physical properties or performance. Testing usually consists of determining the lubricant's effect on jacket tensile strength, elongation, dielectric strength, volume resistivity and stress cracking.

A great variety of performance requirements for pulling lubricants come from end users. Such practical issues as pulling through water, adhesion to cable jacket, temperature stability and even odor are considered important by end users.

Surprisingly, an area of cable lubricant performance that has not been discussed much or measured until now is combustibility. Cable pulling lubricants, or, actually, their residues, are as real a part of a conduit system as the cable or conduit itself. The combustion character of the cable and conduit has been the subject of numerous studies and standards designed to minimize their contribution to the intensity or spread of a fire.

The nuclear industry has made some attempts to measure fire parameters of lubricant residues. A number of conventional cable flame tests have been adapted to lubricants. The approach has been to put typical amounts of lubricant on a fire retardant cable. The lubricant is allowed to dry. Then the lubricated cable and a non-lubricated control are subjected to the flame test to determine any lubricant effect.

When tested in this fashion, many of the Hydrocarbon Wax lubricant residues simply melt and drop into the flame. This does not duplicate the real conditions under which these residues would be exposed to fire. Such testing does not show the very significant differences in the combustibility of lubricants.

The purpose of this research was to develop a more realistic fire performance testing procedure for cable lubricant residues. Additionally, we wanted to quantify flame propagation and combustion differences among lubricant residues.

TEST METHOD AND SAMPLES

Cable Lubricant Types and Their Residues

A wide variety of cable pulling lubricants are used throughout the world. A number of these lubricants are manufactured and marketed specifically for cable pulling. Occasionally, automotive grease or even dish soap is used.

With high-performance plastic and rubber cable jackets becoming more and more common, the worldwide trend is to use lubricants proven to be compatible with these materials. These lubricants can be generally categorized as follows:

1) Polymer/Water Solutions: Low solids materials ($<$ 5% residue by weight) which have extremely low friction based on high molecular weight polymers dissolved in water.

2) Wax Emulsions: Various types of hydrocarbon waxes emulsified in water. Solids content (residue) is 15-30% by weight.

3) Soaps: Salts of various fats or oils, often dissolved in water. Solid residue can vary significantly (20-80% by weight).

4) Bentonite Clay Slurries: Finely divided, inorganic, bentonite clay slurried in water/glycol solutions. Residue is 12-25% by weight.

5) Dry Powders: Talc or other inorganic powder base. 100% solids with no evaporating component.

How Lubricants are Used — Fire Exposure

Cable pulling lubricants are applied to cable jackets or coated on conduit walls in sufficient quantity to lower the friction and tension on the cable as it is pulled. The lubricant ends up distributed (perhaps unevenly) throughout the conduit.

The amount of lubricant in the conduit varies. Typically, the more difficult the pull (the higher the expected tension), the more lubricant is used. Experienced cable pullers know that length of run, cable weight, conduit fill, jacket/conduit type, and number/degree of conduit bends are all factors that determine the appropriate amount of lubricant to use. In industrial pulling, lubricant usage can vary from .3 to as much as 6 gallons per 100 feet of conduit. At typical lubricant densities, this is 10 to 200 grams of lubricant per foot of conduit.

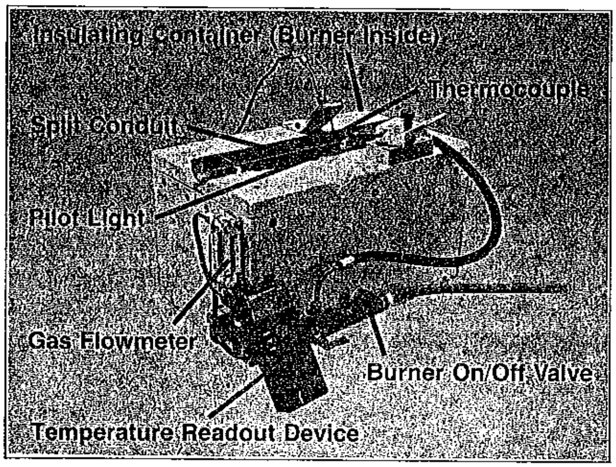
After use, the volatiles in the lubricant (water, glycerine, glycol) evaporate leaving only the residue in the conduit. In the case of a fire, this residue is heated but **contained** by the conduit system. Depending on the residue combustion character, it can ignite and spread fire through the conduit.

Fire spreading through conduit systems is not new. Non-flammable conduit, fire retardant jackets, fire stops, etc., are used to prevent such spread. How do cable lubricant residues perform relative to these better known cable and conduit materials?

Test Apparatus

To simulate field exposure, and to evaluate the performance of lubricant residues under fire conditions, the device shown in Figure 1 was built.

Figure 1



The device generates heat from a gas burner roughly one foot in length, which is contained in a non-combustible box. The burner heats a rigid steel conduit split in half with welded end caps to retain the lubricant. Specifically, 2" rigid conduit was placed over a 2" x 12" slot in the box to yield an area for heat impingement of 24 square inches (.01548m^2).

A flow meter was used to control the gas burn rate and the heat flux from the burner. 2.25 cubic feet per hour (cfh) was the lowest gas flow rate which would maintain a continuous burner flame. This converted to a minimum heat flux of 42 KW/m^2, which was focused on the split conduit/residue sample.

An iron/constantan thermocouple was inserted **into** the residue (when possible) to measure its temperature. Finally, a pilot light (also gas) was devised which could be brought in from above the conduit to direct a flame onto the contents to attempt ignition.

Lubricants Evaluated

Commercially available cable lubricants were evaluated. No powder lubricants (talc type) were represented. Inorganic powders are poor friction reducers and thus are not commonly used or available commercially for cable lubrication.

The lubricants selected are in Table 1:

TABLE 1

Lubricants Used in Combustion Testing

Lubricant Designation	Color	Appearance	% Solids*
High-performance Gel Polymer Lube	Off-white	Thick, translucent gel	3.3%
Wax Lube #1	Yellow	Particulate paste	14.0%
Wax Lube #2	Yellow	Smooth, pearly appearance, flowable	14.1%
Wax Lube #3	Yellow-beige	Chunky paste	10.4%
Wax Lube #4	Yellow	Smooth, pearly appearance, flowable	13.7%
Fluffed (air filled) Wax/Soap Lube	Cream-tan	Low density paste	15.4%
Polymer/Teflon Lube	Red	Thick, pourable liquid	2.2%
Wax/Soap Lube	Light green	Very thick, flowable	12.3%
Bentonite Slurry Lube	Tan-brown	Thick paste	13.4%
Polymer Lube	Colorless	Clear, thick gel	1.1%

*The percent solid residue was determined for all samples by open drying in a 105°C (221°F) oven for 24 hours. This percent solid data was used to insure that later lube residue samples were "dry" when tested.

Test Sample Preparation

The test samples were prepared by evenly distributing 200 grams of wet lubricant in the foot-long, split conduit. The lubricant was dried (typically one day at 105°C) and percent solids determined to ensure drying.

This procedure duplicated the field situation of dried lubricant dispersed throughout a conduit system. While 200 grams per foot is a high lubricant usage, it is not unrealistic. As data shows later, the use of smaller quantities of lube somewhat shortens burn times, but does not affect ignition or flame propagation character.

There were, of course, significant differences in the amount and appearance of the residue after drying. The conduit containing each residue sample was put on the heating device described earlier to conduct the tests.

To provide a control for the test results, 20 gms. of Hypalon Cable Jacket were tested using the same methods, but without lubricant. This jacket was taken from a Class 1E nuclear qualified cable that was fire retardant. The jacket was stripped from the cable and cut into ¼" squares for the test.

COMBUSTION DATA

Ignition Measurements

These measurements were made to determine the ease of ignition of each residue. None of the residues would ignite with only a match and no outside heat source. Therefore, none are "flammable" in the common sense of the word. Many, however, are "combustible" as will be shown.

Using an approach described by Factory Mutual Research, several heat fluxes (heating levels) were focussed on the split conduit/lubricant residue by varying the gas burn. The purpose was to determine the size of the fire source, if any, needed to ignite the lubricant residue. Based on Factory Mutual work with cable jackets, three different heat fluxes (gas burn rate) were chosen. These were 2.25 cfh (42 KW/m^2), 3.25 cfh (61 KW/m^2) and 4.5 cfh (85 KW/m^2).

At a given flame setting (heat flux), the split conduit with dried lube was placed over the flame and time to ignition was measured. The thermocouple was inserted into the residue and temperature was also monitored. Ignition was induced by briefly impinging the pilot flame on the residue sample at 30-second intervals. Ignition was defined as a sustained flame for at least 5 seconds after removal of the pilot light. With most of the samples, the pilot produced the ignition. Occasionally, at the high heat fluxes, the Hydrocarbon Wax Lubricants would spontaneously ignite (without the pilot).

The heating was continued for 30 minutes. If a sample ignited, burned for a short while and then self-extinguished, the pilot was again applied at 30-second intervals to try to ignite a different area of the sample. Data from these ignition tests are presented in Figures 2, 3 and 4 and Table 2 below.

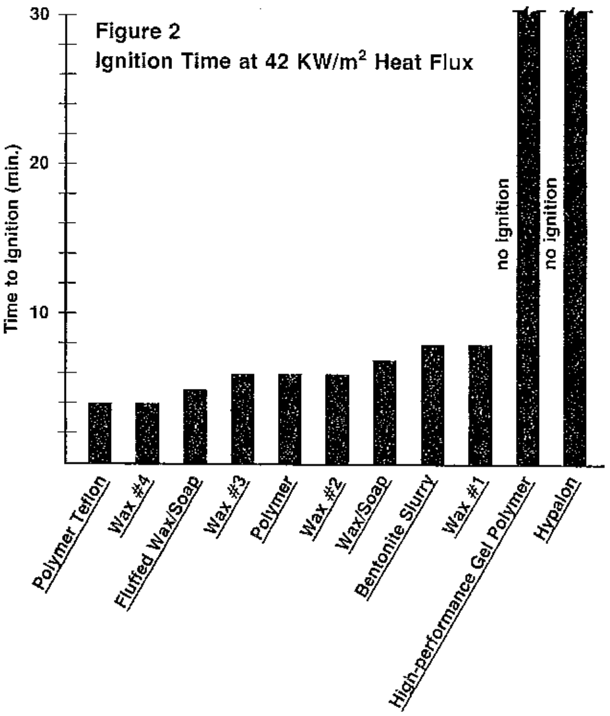


Figure 2
Ignition Time at 42 KW/m^2 Heat Flux

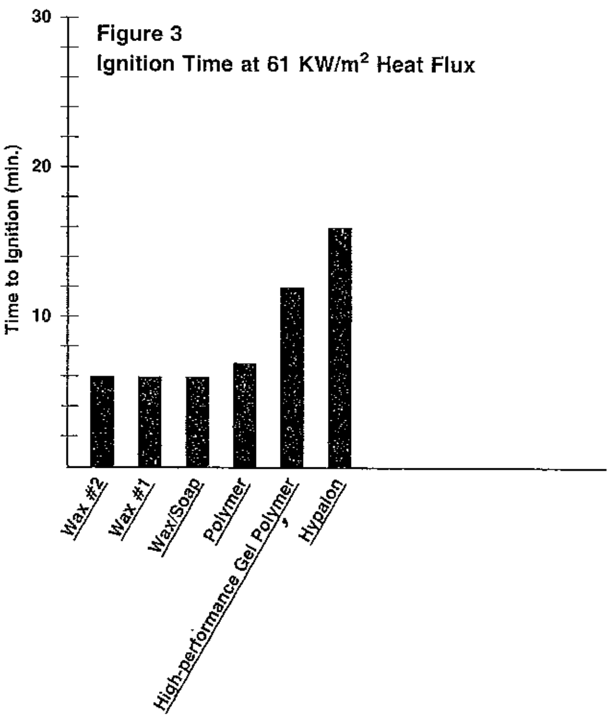


Figure 3
Ignition Time at 61 KW/m^2 Heat Flux

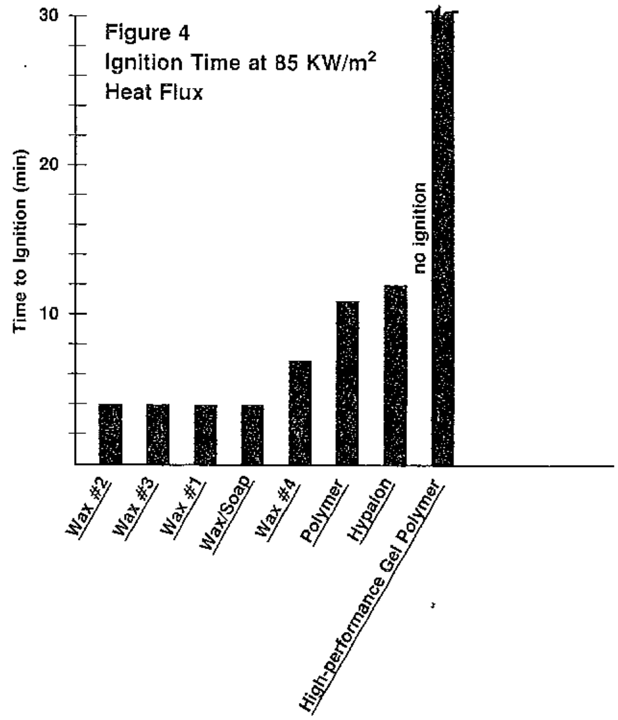


Figure 4
Ignition Time at 85 KW/m^2 Heat Flux

TABLE 2

Temperature at Ignition and Ignition Energy (Calculated) for Various Heat Fluxes

Lubricant	42 KW/m^2 Flux		61 KW/m^2 Flux		85 KW/m^2 Flux	
	Temp (°C)	Ignition Energy (KJ/m^2)	Temp (°C)	Ignition Energy (KJ/m^2)	Temp (°C)	Ignition Energy (KJ/m^2)
High Performance Gel Polymer	No Ignition	No Ignition (>74,000)	285°	44,000	No Ignition	No Ignition (>150,000)
Wax #1	260°	20,000	250°	18,000	230°	20,000
Wax #2	290°	15,000	230°	18,000	250°	20,000
Wax #3	250°	15,000	—	—	350°	20,000
Wax #4	200°	9,800	—	—	340°	36,000
Fluffed Wax/Soap	200°	12,000	—	—	—	—
Polymer/Teflon	200°	9,800	—	—	—	—
Wax/Soap	280°	17,000	290°	18,000	260°	20,000
Bentonite Slurry	240°	20,000	—	—	—	—
Polymer	320°	15,000	300°	27,000	380°	56,000
Hypalon	No Ignition	No Ignition (>74,000)	280°	58,000	280°	61,000

To understand this data, we must review a few concepts. Critical heat flux is defined as the heat flux (in KW/m^2) below which samples will not ignite. In a fire, heat flux represents the intensity of the outside fire source. The gas burner would not function at gas flows under 2.25 cfh, which limited our minimum heat flux to 42 KW/m^2. As Figure 2 shows, all samples could be ignited at 42 KW/m^2 except the High-performance Gel Polymer Lube and the Hypalon Jacket control.

Ignition energy, shown in Table 2, is defined as the heat flux multiplied by the time to ignition. It is expressed in KJ/m^2 and represents the amount of energy required to heat the lubricant residue to ignition temperature. This, in turn, is related to the quantity, specific heat and thermal conductivity properties of the lubricant residue.

The data show significant differences in the ignition properties of the lubricant residues. The Wax and Wax/Soap Lubes have critical heat fluxes well under 40 KW/m^2 and ignition energies under 20,000 KJ/m^2. They ignite at temperatures between 200° and 300°C.

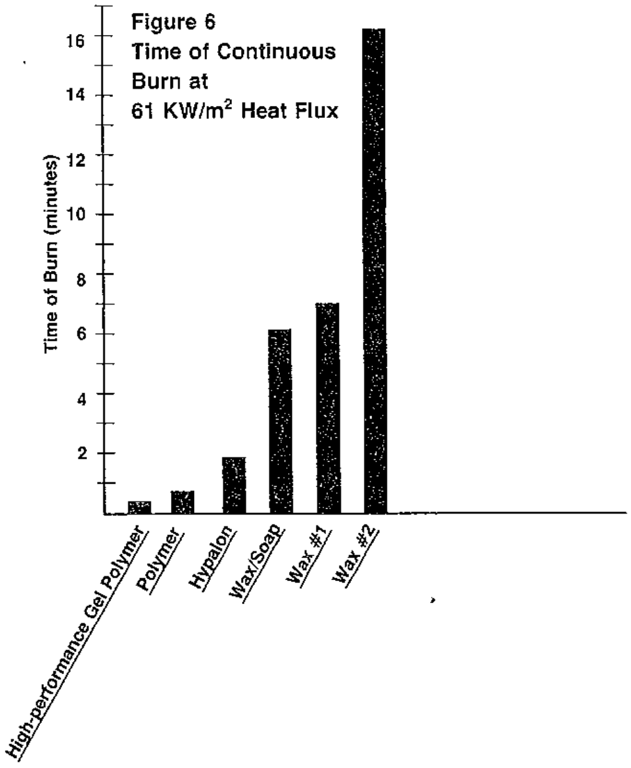
The Hypalon Cable Jacket and the High-performance Gel Polymer Lube have critical heat fluxes above 40 KW/m^2 and ignition energies above 50,000 KJ/m^2. We could not determine a consistent critical heat flux for the High-performance Gel Polymer since it ignited briefly at 61 KW/m^2, but would not ignite at 85 KW/m^2. Regardless, the Hypalon Jacket control and High-performance Gel Polymer were clearly much harder to ignite than the other lubricants tested.

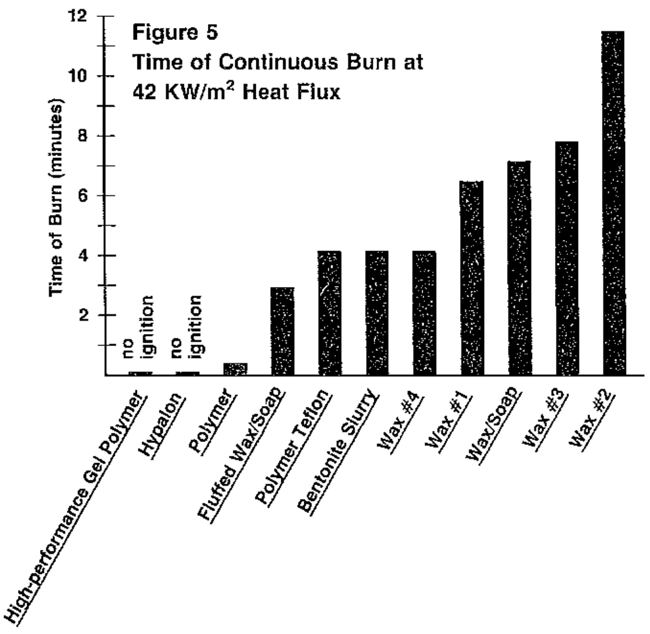
We should note that the Bentonite Clay Lubricant ignition seems illogical. However, these lubes contain ethylene glycol, which is what burned.

Flame Propagation & Burn Times —
Continued Outside Heat Source

Once a residue had ignited (greater than five seconds burn), several additional measurements and observations were made. First, the burn was timed until the flame extinguished. If the flame **spread** through the conduit from the initial ignited area, this was noted. If the flame went out, additional attempts were made to ignite other areas of the residue with the pilot for the full 30 minutes of the test.

Data on burn times and flame propagation are presented in Figures 5, 6, 7 and Table 3 below.





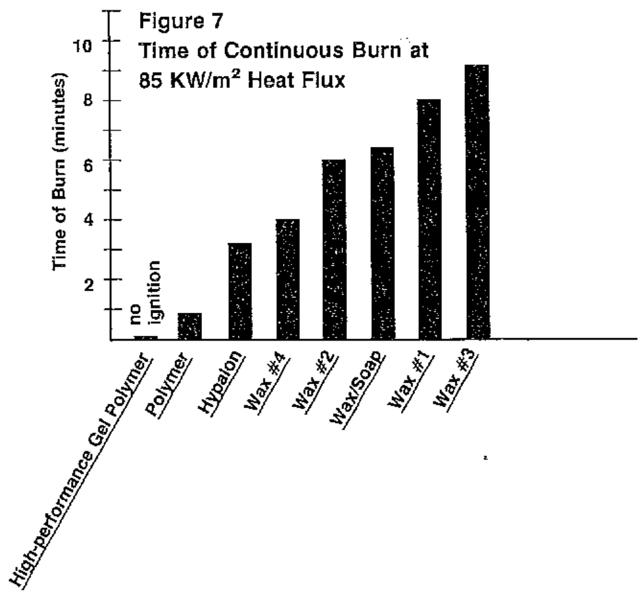


TABLE 3

Flame Propagation at Various Heat Fluxes

Lubricant	Flame Spread @ 42 KW/m²?	Flame Spread @ 61 KW/m²?	Flame Spread @ 85 KW/m²?
High-performance Gel Polymer	No	No	No
Wax #1	Yes	Yes	Yes
Wax #2	Yes	Yes	Yes
Wax #3	Yes	—	Yes
Wax #4	Yes	—	Yes
Fluffed Wax/Soap	Yes	—	—
Polymer/Teflon	Yes	—	—
Wax/Soap	Yes	Yes	Yes
Bentonite Slurry	Yes	—	—
Polymer	No	No	No
Hypalon	No	No	No

The lubricant residues fall into several categories. The Hydrocarbon Wax and Combination Wax Lubes, once ignited, burn freely and at length, allowing the flame to spread throughout the conduit.

The Clay Slurries and Teflon-containing Lube also burn continuously, and spread the flame, although not with such vigor.

Finally, while the Hypalon Jacket, High-performance Gel Polymer and plain Polymer can sometimes be ignited for short time periods at the higher heat flux, they self-extinguish and do not spread flame. The High-performance Gel Polymer Lubricant shows very short, if any, burn times and quick self-extinguishment. The High-performance Gel Polymer Lubricant is, in fact, considerably more fire resistant than the Hypalon Cable Jacket.

Flame Propagation & Burn Time — Discontinued Outside Heat Source

Tests were done where the burner was turned off once the sample had ignited. The lowest heat flux which had previously resulted in ignition was used for these tests. The burning sample was then observed to see if the flame spread throughout the conduit from the point of ignition. Total time of burn was also measured.

This test determines whether the heat produced by combustion of the lubricant residue is sufficient to sustain the flame without any additional outside heat source. In a fire situation, this could result in the spread of the fire into a non-burning area (through a firewall).

The data on burn times and flame propagation are presented in Table 4 below.

TABLE 4

Fire Parameters with Burner Turned Off on Lubricant Ignition

Lubricant	Heat Flux	Time of Burn (Minutes & Seconds)	Spread on Propagation Through Conduit?
High-performance Gel Polymer Lube	61 KW/m²	No Ignition	No
Wax Lube #1	42 KW/m²	10′ 9″	Yes
Polymer/Teflon Lube	42 KW/m²	2′ 0″	Yes
Wax/Soap Lube	42 KW/m²	14′ 0″	Yes
Hypalon Jacket	61 KW/m²	3′ 46″	No

Results show that the Hydrocarbon Wax, Combination Wax and Polymer/Teflon Lubricants burn vigorously even when the outside heat source is removed. The combustion of these lubricants produces enough heat to self-sustain and propagate flame.

The High-performance Gel Polymer Lube would not burn for more than five seconds, barely enough time to turn off the burner. The Hypalon Jacket material did burn for several minutes after the heat flux was removed. The flame did not spread, however.

Residue Quantity

To see how combustion properties changed with a smaller quantity of residue, several of the combustible lubricants were tested with one-half the amount in the test conduit (100 gms.). Results are presented in Table 5.

TABLE 5

Fire Parameters with 100 gram Sample Size

Lubricant	Heat Flux (KW/m²)	Ignition Time	Temperature At Ignition (°C)	Time of Burn (Minutes & Seconds)	Flame Spread Throughout Conduit?
Wax Lube #1	42	6′	220°	6′ 47″	Yes
Wax/Soap Lube	42	6′	270°	5′ 33″	Yes

With half the residue, the results did not differ significantly from before. Ignition times and temperature are similar. Surprisingly, even with the significant decrease in fuel, burn times are down only slightly.

Residue Mobility

It was noted earlier that the Hydrocarbon Wax Lubes melted on heating. Melting data on the lubes are presented in Table 6.

TABLE 6

Melting Data on Lubricant Residues

Lubricant	Liquifies When Heated Above 300°C?
High-performance Gel Polymer Lube	No
Wax Lube #1	Yes
Wax Lube #2	Yes
Wax Lube #3	Yes
Wax Lube #4	Yes
Fluffed Wax/Soap Lube	Yes
Polymer/Teflon Lube	No
Wax/Soap Lube	Yes
Bentonite Slurry Lube	No
Polymer Lube	No
Hypalon Jacket	No

To see if melted lubricant residue would flow and spread flame, a test was run on Wax Lube #1. The residue from 200 grams of Wax Lube #1 was placed in half the length of conduit. The same device and heating procedure (42 KW/m²) was used as before. As expected, the lubricant residue melted (at about 120°C) and flowed through the conduit. The flowing residue ignited at 240°C. The flame was then spread by the mobile fluid through the entire length of the conduit.

CONCLUSIONS:

Significant differences can be observed in the combustibility of lubricant residues.

The Wax and Combination Wax/Soap Lubricant residues are combustible. They ignite at heat fluxes below 40 KW/m^2 and temperatures of 200°-300°C. Once the wax residue is ignited, the flame sustains itself without any outside heat source. Flame will also spread along these residues. This flame movement is accelerated if the residue melts and flows.

There are a number of other lubricants — Polymer/Teflon, Bentonite Clay/Glycol Slurries — which can also be ignited but do not burn as vigorously nor as long (lower solids). These also spread flame once ignited.

Finally, there was one lubricant which showed little tendency to ignite or burn; in fact, less tendency than fire retardant cable jacket. This was the High-performance Gel Polymer Lube.

The ignition behavior of the lubricant residues is specific to the residue, rather than its quantity. Some residues were quite combustible, with only one demonstrating outstanding fire resistance.

A secondary factor is the quantity of the residue remaining. This quantity is directly proportional to the percent non-volatiles (% solids) of the lubricant. Lubricants with **very low solids** (<1%) don't seem to have enough residue to propagate or spread flame, even if their residues can be ignited.

In applications where the spread of fire is of concern, and particularly where fire-retardant cables are used in conduit, care should be used in selecting a lubricant. One approach is to select lubricants which are less combustible than the cable itself. Based on this approach, suggested performance criteria for such a lubricant (residue) would be:

1) Will not ignite for more than 10 seconds at a 40 KW/m^2 heat flux or at a 315°C temperature (200 gm. sample).

2) At a heat flux of 60 KW/m^2, will not burn for more than 60 seconds after removal of heat source (200 gm. sample).

3) Will not melt or flow when heated to 350°C.

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