

# Napalm



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The thickening agent employed by the Chemical Warfare Service, U. S. Army, for the preparation of gelled gasoline fuels used as filling for incendiary bombs and in flame throwers is an aluminum soap derived from a combination of acids of the types exemplified by lauric acid and by naphthenic or oleic acid. A description is given of early work on the problem conducted under the National Defense Research Committee in cooperation with Edgewood Arsenal. ~Photo above shows operation of a portable flame thrower utilizing Napalm fuel (reproduced through courtesy of Standard Oil Development Company).

IN MILITARY idiom the name Napalm has been used to designate either a special aluminum soap employed by Chemical Warfare Service as a thickening agent, a gasoline gel produced with this agent and used as a flame thrower fuel and for filling the M-69 and M-47 bombs and other incendiary munitions, or even a Napalm gel-filled incendiary itself: "One Napalm (fire bomb) on target. . . ." In this paper an account will be given of early work conducted at the Gibbs Laboratory in cooperation with the Chemical Warfare Service group at Edgewood Arsenal, Md., on the development of Napalm-type gelling agents. The subsequent work on the manufacture, standardization, and stabilization of the eventual product was carried to a successful conclusion through the combined efforts of Chemical Warfare Service laboratories, manufacturers, and NDRC groups other than our own; this report will describe merely the initial research conducted in 1941-42.

The background for the research was provided by an interesting series of circumstances starting, in the summer of 1941, with

an exploration of possible military uses of divinylacetylene. This hydrocarbon is capable of undergoing peroxidation to products that have occasionally exhibited either explosive or inflammatory properties, but our attempts to produce material of regularly destructive character were without avail. We observed, however, that when either divinylacetylene or the commercial polymer known as Synthetic Drying Oil was shaken with oxygen, transformation occurred to a peroxide-containing sticky gel. When ignited with a match, this gel burned with a sputtering, spectacular flame, and trials in simulated explosion- or scatter-type bombs convinced us of the potential value of a gelled hydrocarbon fuel that would be distributed over a target area in the form of burning, adherent masses. Major Gerrard Rambaut, of the British Air Ministry, encouraged the continuation of work on incendiary gels; he told of the parallel development of rubber-benzene gels in England and advised that some test be worked out for evaluating incendiary materials. A method that proved to be a useful guide was soon introduced and eventually refined: A standard volume of gel dispensed from a modified grease gun was burned in a draft-free room on a wooden structure consisting of a base-board provided with four 2 × 4 inch uprights connected by crossbeams, and the results were expressed in terms of the weight of wood destroyed and the burning time. Such burning tests soon provided evidence that the gels from divinylacetylene, even when fortified with chlorates or nitrates, were more spectacular than effective. Rubber gels proved to be better; consequently, extensive studies were made in the fall and winter of 1941 on the preparation and incendiary properties of 6-8% gels of smoked sheet, crepe, and latex rubber in gasolines, naphthas, and other less available hydrocarbon fuels. During this period bombing tests conducted at Edgewood Arsenal established the practicality of employing a rubber-gasoline gel as a filling for the available M-47 100-pound bomb. Then came Pearl Harbor and the sudden cancellation of rubber from the list of available stores. In response

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to a request received a few days later from the chief of the Technical Division, Chemical Warfare Service, work on rubber gels was stopped at once, and an empirical search for some other gelling agent was started.

The requirements were severe. The thickening agent had to be compounded from abundantly available starting materials (eventual production reached a scale of about 75 million pounds per year). The gel had to be easily ignitable and burn efficiently, and be sufficiently tough and stringy to withstand the blast of an explosive charge and not shatter. It could not thin out at 150° F. or become brittle at -40° F., and had to be stable in storage and withstand cyclic temperature changes and shaking. A further specification was that the process of preparing the gel be adaptable to a simple field-filling operation. Actually, the plans were later changed and the bombs for which Napalm and other gels were designed were all loaded at the site of manufacture or in local arsenals. However, the early insistence on field filling turned out to have been a fortunate decision when gelled fuels came to be used in flame throwers and belly tanks.

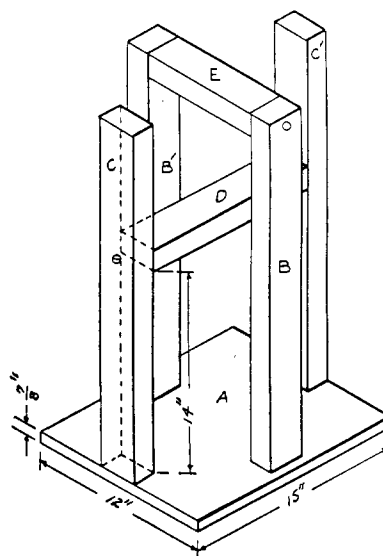
The known metal soaps initially appeared unpromising; for example, aluminum stearate can be incorporated into gasoline satisfactorily only by heat treatment, and the resulting gels are hard and friable and lack the adhesive and cohesive properties desired. The first gels that seemed to have some of the character of the rubber gels with which we were familiar were two samples prepared by a cooperating group of Arthur D. Little, Inc. One was an 8% gel of aluminum naphthenate in gasoline prepared by a heating process. The other was a 5% gel prepared in the cold from an alcohol-washed aluminum naphthenate. Both gels seemed to have the stringy consistency desired, but the first was incompatible with the field-filling requirement and the second was soon ruled out by a report from a manufacturer indicating that the alcohol washing could not be conducted on a large scale without great loss and expense. We therefore sought comparable agents or combinations capable of low-temperature gelation, or some method of incorporating the commercially available soft gums of aluminum naphthenate or aluminum oleate into gasoline without recourse to special processing or heat treatment.

Attention was directed to a product marketed under the name "aluminum palmitate" because of the manufacturer's claim that this soap would form gels with hydrocarbons at low temperatures. Actually, gelation in gasoline was found to proceed very slowly at room temperature, and the gels proved to be feeble and unstable. However, it was observed (January 23, 1942) that the addition of a free fatty acid caused rapid setting to a full-bodied thermostable gel. Unsaturated acids, such as oleic or oleic-linoleic, seemed particularly efficacious as plasticizers, and hence the gels obtained from the combination of the supposed "palmitate" and an "enic" acid were designated Palmene gels. It was next found (January 29, 1942) that a combination of aluminum naphthenate with the same "aluminum palmitate" could be easily incorporated into gasoline to form a promising gel, and we termed this naphthenate-"palmitate" combination a Napalm gel. Subsequently it developed that the supposed "aluminum palmitate" was actually the aluminum soap of the total fatty acids of coconut oil, and that the specific gelling quality is due to a high content of lauric, not palmitic, acid. The names "Napalm" and "Palmene" (and "Oleopalm") are thus misnomers, but since the first name has become firmly entrenched as a designation of a specific, improved formulation, the original, fortuitously derived names will be retained in the following summary.

## PALMENE GELS

Gels in gasoline or kerosene were prepared by mixing the aluminum soap of the total coconut oil acids (e.g., "aluminum palmitate" Metasap) with the fuel to produce a slurry, adding the fatty acid component, and agitating the mixture at ordinary temperature (15-25° C.) for a short time, either by stirring or by cyclizing through a gear pump homogenizer. An initial stiff gel is produced in less than one hour and changes to a more stringy consistency in about 15 hours. Successful formulations in gasoline contained 5-9% aluminum coconut oil acid soap (Al-COA) and 2-5% of Armour's Neo-Fat 3R (40% oleic, 60% linoleic). A 7% Al-COA-4% Neo-Fat 3R gel withstood cycling between -40° and 52° C., showed good body and stringiness throughout this range, and in the standard burning test had an average value of 402 (grams of wood destroyed) as compared with the value of 493 for 6% crepe rubber in the same commercial grade of motor gasoline. The addition of 2% lampblack to the same gel raised the burning test value to 531. Neo-Fat 19 (C<sub>20</sub> acids with three and four double bonds) proved about as satisfactory as Neo-Fat 3R, whereas Neo-Fat 17 (C<sub>20</sub> and C<sub>22</sub> unsaturated acids) gave rather brittle gels. Gels prepared with oleic acid as plasticizer were less satisfactory at low and high temperatures. Linseed oil acid gave gels of initially satisfactory properties but of dubious stability on storage. A gel containing 2% naphthenic acid and 5% Al-COA soap was unduly thin, but the addition of 1% Poly Pale resin (Hercules Powder Company's abietic acid derivative) gave a full-bodied but somewhat brittle gel. The best formulation found for a bomb filling contained 9% Al-COA soap, 5% Neo-Fat 3R, and 2% lampblack; this gel was fairly tough and durable and probably suitable for a tail-ejection bomb, but dropping tests conducted in the M-47 bomb at Edgewood Arsenal on February 25, 1942, showed that the gel was not stringy and tough enough to withstand a black powder explosion.

In another series (Table I) the acid component was kept constant, and the composition of the aluminum soap was varied. The results show that lauric acid is a key component of the soap but that synthetic acids offer some promise of serving as substitutes (Table I, e and f).



Posts B, B', C, C', 1 1/2 x 2 1/2 x 24 inches;  
bar D, 1 1/2 x 2 1/2 x 12 inches; bar E,  
1 1/2 x 2 1/2 x 7 inches



## Burning Test for the Evaluation of Incendiaries

A 97.3-cc. sample of gel is dispensed from a calibrated grease gun and burned on a standard structure in a draft-free room; the loss in weight of the structure and the burning time are measured.

## EARLY NAPALM AND OLEOPALM GELS

These gels were prepared by first adding chunks of commercial aluminum naphthenate or oleate gum to a charge of gasoline while it was being circulated through a gear pump; when the gum had all dissolved, a quantity of aluminum coconut acid soap was added slowly and the temperature was brought to 28° C. by friction from the pump. A satisfactory gel was produced in 20 to 30 minutes and required little subsequent aging to reach a permanent state. If a filler is added after the naphthenate or oleate has dissolved, it increases somewhat the incendiary effectiveness of the gel.

The gels listed in Table II were all tough and stringy, and retained this character at -40° to 52° C.; they performed well in explosion tests in simulated bombs. Two field-filling processes were devised and demonstrated at Edgewood Arsenal on March 20, 1942 (and dropping tests were conducted a few days later): (1) A slurry of 2.1 pounds of aluminum coconut oil acid soap and 6.9 ounces of lampblack in 4.4 gallons of gasoline was poured into an M-47 bomb, followed by 2.25 gallons of a 16% solution of aluminum naphthenate in gasoline. (2) Napalm powder was made by incorporating dried wood flour (1.88 pounds) with aluminum naphthenate (2.36 pounds) in a meat grinder and milling aluminum coconut oil acid soap (2.36 pounds) into this material in a Simpson mixer; the resulting granular product can be mixed with gasoline in the bomb, for gelation sets in within a few minutes, and a homogeneous, stable gel is produced in 5 to 6 hours (burning test value, 645).

## NAPALM POLYMER

This improved form of Napalm-type thickener, developed about March 23, 1942, was prepared as follows: A 5-pound charge of aluminum naphthenate (Nuodex) was milled for a few minutes in a steam-jacketed mixer at a steam pressure of 5 pounds until it became sticky and doughy; an even slurry of 5 pounds of aluminum coconut oil acid soap in 10 pounds of Diesel fuel (or kerosene) was then poured in slowly at such a rate as to keep the mix doughy and avoid a local excess of unmilled fuel. The cover was put in place, and the mix milled for 30 minutes at a temperature increasing from 75-85° C. in 15 minutes to 95-100° C. (not higher) at the end of the period. The resulting product was a soft gum.

For the preparation of an incendiary gel, 5.7 pounds of the Napalm polymer gum were put through a Hobart meat grinder

TABLE I. GASOLINE GELS CONTAINING 4% NEO-FAT 3R (NF3R) AND 7% ALUMINUM SOAP

No.	Component Acids of Soap	Character of Gel
a	50 lauric, 20 myristic, 10 palmitic, 5 stearic, 15 NF3R	Tough and stringy, good stability from -40° to 52° C.
b	55 myristic, 20 palmitic, 10 stearic, 10 NF3R, 5 naphthenic	Good at -40° C., rather thin at 52°
c	70 myristic, 10 palmitic, 5 stearic, 15 NF3R	Slightly short at -40° to 25° C., thin at 52° C.
d	45 myristic, 20 palmitic, 5 stearic, 15 NF3R, 15 naphthenic	Stringy but somewhat thin
e	50 2-ethylhexoic, 20 myristic, 10 palmitic, 5 stearic, 15 NF3R Hydronaphthalenedicarboxylic acids (Du Pont)	Very full-bodied, fairly stringy Very thick, jelly-like

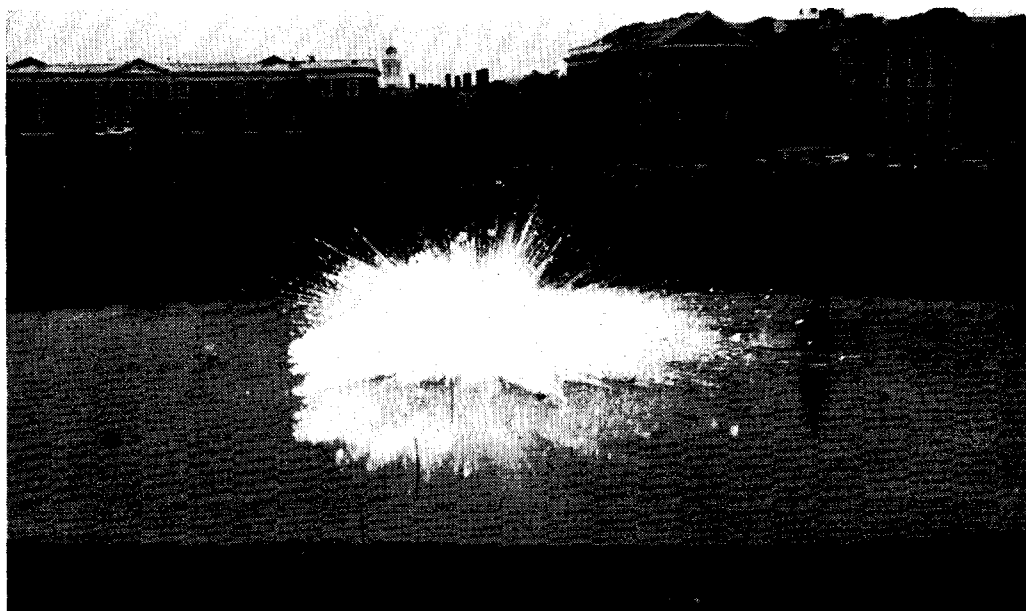
TABLE II. GELS IN GASOLINE

No.	Components	Burning Test Value*
a	5% Al coconut acid soap, 5% Al naphthenate (Shepherd, contains oil)	440
b	Same, plus 1% lampblack	530
c	Same, plus 1% sawdust	546
d	5% Al coconut acid soap, 3% Al naphthenate (Nuodex), 5% lampblack	477
e	4% Al coconut acid soap, 5% Al oleate (Shepherd or Cyanamid), 1% lampblack	543

\* 6% crepe rubber = 493.

equipped with a delivery plate having 1/8-inch holes; the issuing stream of spaghetti-like strands was run directly into a mixer containing 13.5 pounds of gasoline that was being circulated by means of a gear pump. After 15-20 minutes the soap had become solvated to an even suspension and could then be run into a bomb casing; after standing for 5 to 6 hours, final gelation had occurred and the gel was ready for use.

This gel had excellent stability in the range from -40° to 153° F., and inspection at -40° F. revealed no tendency to turn brittle or to undergo syneresis on vigorous agitation. The material without an added filler showed the high value of 588 in the burning test. Static firing tests in Cambridge and bombing tests by the Chemical Warfare Service at the Edgewood and Huntsville Arsenals in the M-47 and M-69 bombs showed that the gel was distinctly tougher and more resistant to the shattering action of an explosive charge than any of the earlier gels described above. Pilot plant batches of the polymer gum were prepared without difficulty by a manufacturer of metal soaps (Nu-



This Napalm-Filled Bomb, Fitted with a White Phosphorus-TNT Burster, Has Just Been Statically Fired over Water to Determine the Percentage Loss of Fuel Due to Flash Burn. The Gel Was Distributed over an Area 60 Yards in Diameter, and 95.6% of it Was Recovered.

dex), and the preparation of the gasoline gel was found adaptable to a plant-filling process. Indeed, the gel was very superior in quality, and the thickener met all of the requirements except that of adaptability to a field-filling operation.

#### COPRECIPITATED NAPALM

An improvement that supplied the one remaining feature was contributed by A. Minich of Nuodex Products Company, Inc., who had undertaken the production of the pilot plant batches of Napalm polymer, and who suggested that the Napalm-type soaps might be obtainable in solid form by application of a known process of precipitation from excess alkali by which aluminum naphthenates had been produced as (low-melting) solids (1, 3). A series of trial formulations was agreed upon (March 31) on the basis of our past experience with the various Napalms and Oleopalms and from a consideration of the possible shortage of naphthenic acid; samples were subsequently prepared by Nuodex both by the polymer process and by coprecipitation, and were sent to us for evaluation. The most promising sample was a granular aluminum soap prepared by the precipitation method from two parts of coconut oil acid, one part of naphthenic acid, and one part of oleic acid (sample X-104), for example, as follows: To a solution of 132 pounds of coconut acid and 66 pounds each of naphthenic and oleic acids in 225 gallons of water containing 280 pounds of 25% sodium hydroxide solution, was added a solution of 198 pounds of aluminum sulfate crystals in 25 gallons of water; the precipitated magma was washed thoroughly and dried at a temperature not exceeding 150° F. Yield was 270 pounds. The resulting Napalm soap was a dry, nonsticky solid that solvated and gelled rapidly in gasoline or kerosene and gave gels comparable in quality and general characteristics to the Napalm polymer gels. The precipitated solid was clearly the more easily handled and used, and this form of Napalm was eventually adopted by the Chemical Warfare Service.

The early measurements and characterizations of gels obtained with the 2-1-1 precipitated formulation will not be recorded in detail, for more extensive data are now available from other laboratories. One point will be mentioned in connection with particle size. A typical soap sample, when ground to a fine powder, had a dispersion time in gasoline of 15 seconds and a setting time (after which the mixture is unpourable) of 30 seconds. When the same material was compressed by hand into 1/8-inch pellets, the respective times were 11 and 60 minutes. Pellets compressed in the same way from a mixture of the Napalm soap with 1% dried wood flour showed a dispersion time of 3 minutes and a setting time of 5 1/2 minutes. The same soap without a filler, when compressed on a roller at 5000 pounds per square inch and screened to 8 mesh, had a dispersion time of 9 minutes and a setting time of 13 minutes. It was observed also that the time required for gelation varies considerably with the nature of the solvent; typical setting times noted in the preparation of 12% gels were as follows: gasoline, 1 minute; hexane fraction, 9; isooctane, 25; benzene 1.5; cyclohexane, 2 minutes.

With an apparently satisfactory solution of the problem at hand, it seemed desirable to explore the possibility of employing alternate acidic components as substitutes for coconut oil acid and naphthenic acid in case adequate supplies of these critical materials should not be available. Table III reports comparative results on soaps made by the 2-1-1 formulation with acids derived from the three high-lauric oils—coconut, babassu, and palm kernel. The soaps were prepared by the procedure described and dried to a moisture content of 0.5-2.0%, as determined by the loss in weight on drying a sample at 70° C. and 20 mm. pressure for 48 hours. The average ash content was 13.2% and the average aluminum content 5.9%. The soaps prepared from the three nut oil acids all gave 12% gels of high quality, and the differences noted between them were of a minor nature.

In other trials, samples of refined naphthenic acid were used of acid number ranging from 230 to 243 and containing from 2 to



COURTESY, STANDARD OIL DEVELOPMENT COMPANY

#### Japanese-Type Structure Several Minutes after a Napalm-Filled Bomb Was Fired Statically in the Interior

8% unsaponifiable material; and little difference was observed in the gelling properties of the soaps. When unrefined naphthenic acid was employed, the soap was dark brown and produced gels with full body but little stringiness or strength.

In another series the saturated fatty acid component was varied by employing a number of commercial fractions from coconut oil acids and from acids of animal and fish oils (Table IV). All of the special acids of lauric content equal to or greater than that of coconut oil acid gave soaps of satisfactory gelling properties. The poor quality of soap *h* (Table IV) from 90% myristic acid shows that this higher homolog is not a suitable substitute for lauric acid.

A substantial increase in lauric content above that of coconut oil acid results, for one thing, in an increased speed of solvation and setting in hydrocarbon solvents, as illustrated in Table V (the soaps are lettered according to the component fatty acids and are indicated by table number).

Another characteristic of soaps prepared from a saturated acid component rich in lauric acid is that less thickener is required to produce a gel of given viscosity. This and other characteristics of the soaps in this series are indicated in the following descriptions.

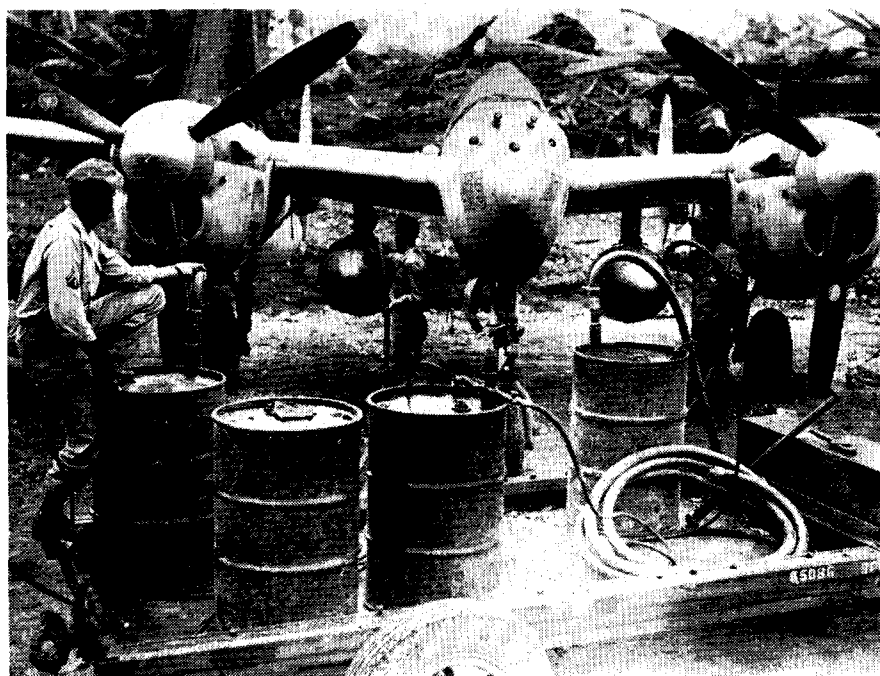
TABLE III. COPRECIPITATED ALUMINUM SOAPS FROM 2-1-1 FORMULATION<sup>a</sup>

	Nut Oil Acid		
	Coconut	Babassu	Palm kernel
Acid analysis			
Acid No.	271.7	261.5	259.0
Saponification No.	270.6	260.2	258.2
Titer, ° C.	23.5	22.4	23.1
Iodine No.	8.2	17.5	17.0
Unsaponifiables, %	0.26	0.28	0.30
Probable lauric, %	47.1	41.9	50.0
Character of 12% gels in gasoline <sup>b</sup>			
Stringiness and body			
At -40° F.	++++	++++	++++
At 125° F.	+++	++++	++++
Stoermer viscosity at 650-g. load <sup>c</sup> , r.p.m.			
Initial	0.092	0.051	0.043
After aging at 125° F.	0.11	0.03	0.03

<sup>a</sup> 2 parts total nut oil split acids, 1 part naphthenic acid (refined, acid 237 unsaponifiable content 8%), 1 part oleic acid.

<sup>b</sup> Reid vapor pressure, 11.5; aniline point, 140° F.

<sup>c</sup> A standard instrument was used with a rotating inverted cup.



U. S. ARMY A.A.F. PHOTO

Twin Belly Tanks of This P-38 Lightning Were Filled with Napalm Gel Transferred from the Drums by Air Pressure. These Tanks Were Jettisoned over Japanese Targets.

A freshly prepared 13.5% gel from soap IVa (Wecoline AAAR) in gasoline was somewhat short, but after 5 days it had acquired excellent characteristics and was tough and reasonably tacky. No syneresis, thinning, or other deterioration was observed in heating tests conducted at 66° C. for periods as long as 700 hours. A 12% gel has approximately the same viscosity as a 13.5% gel of soap IIIa compounded from total coconut oil acid. Soaps IVb to IVf have much the same character as that described.

Soap IVg, prepared with a fatty acid component consisting almost solely of lauric acid, has even greater bodying power. Thus a 13.5% gel is so full-bodied as to be somewhat short and brittle, and better gels are obtained with a lower content of thickening agent. A concentration between 10 and 11% gives a viscosity comparable to that of a 13.5% gel from the "standard" soap IIIa.

Soap IVh, derived from 90% myristic acid (Table IV), is unsatisfactory; a 13.5% gel has satisfactory properties at room temperature but becomes weak and runny at 66° C. In the series of soaps utilizing fish oil acids (Table IV), a similar superiority of lauric over myristic acid is evident. Soap IVi, made from a high-lauric cut, has good bodying power and is generally superior to soap IVj, in which myristic acid predominates. The latter soap, however, is still good enough to be rated as "satisfactory", as is soap IVl, in which part of the lauric acid content is made up by myristic acid. Soap IVk, which is low in myristic acid and contains no lauric acid, is definitely unsatisfactory.

Although oleic acid is abundantly available and is a fully satisfactory component of the standard Napalm formula-

tion, a brief survey was made to test the adequacy of various substitute components. The soaps listed in Table VI were evaluated by inspection of 13.5% gasoline gels at room temperature, -40°, and 66° C.

### DISCUSSION

The better Napalm, Oleopalm, and Palmene soaps described have in common the ability to form hydrocarbon gels at ordinary temperature and to produce gels that are remarkably indifferent to high and low temperatures. Thus the gelling agents, regardless of the physical form or the procedure by which they are incorporated into gasoline, all appear to have the same general functional characteristics. Uniformity is also evident in chemical make-up, for these soaps of the general Napalm type can be considered as compounded from two distinctive components. One is aluminum laurate or a saturated fatty acid soap containing at least 40-50% of this substance or of a functionally related acid soap; this component is a relatively high-melting solid that, by itself, produces only thin and unstable gels. The second component is an aluminum soap or soaps selected from the group including cycloparaf-

finic and unsaturated acids—that is, an aluminum naphthenate, oleate, oleate-linoleate, etc. By itself, the aluminum soap comprising the second component is either a resinous gum or a low-melting solid, and most soaps of this type yield hydrocarbon gels only by heat treatment or by special processing; the resulting gels are not very full-bodied. The combination of an aluminum soap of the laurate type with one or more soaps of the naphthenate-oleate type gives a thickening agent of distinctive and superior properties not found in either component and when prepared by the precipitation process, the soap is a solid of sufficiently high softening point to withstand elevated drying and storage temperatures.

TABLE IV. HIGH-LAURIC AND RELATED FATTY ACID FRACTIONS

No.	Designation	Description	Acid No.	Saponification No.	Titer, ° C.	Iodine No.
From Coconut Oil						
a*	Wecoline AAAR	Residue from stripping lower acids (10%); contains about 8% glycerides	234.0	254.5	25.6	9.2
b*	E. F. Drew special	Total distd. acids + 7% glycerides	233.9	268.7	23.0	7.6
c*	Wecoline AB	Distd. Wecoline AAAR	251.2	252.6	25.4	12.7
d*	Wecoline AAB	High lauric cut	246.9	249.1	25.2	14.6
e*	W. C. Smith	Lauric and higher acids	258.0	259.2	27.9	8.9
f*	W. C. Smith	Lauric-myristic cut	268.8	268.9	31.9	0.7
From Animal or Vegetable Oils						
g*	Neo-Fat 11	90% lauric acid	279.5	279.7	37.8	1.0
h	Neo-Fat 13	90% myristic acid	248	248.2	51	2.0
From Fish Oils						
i*	WCS sperm oil, cut 1	90% lauric acid	273.3	273.0	37.2	0
j*	WCS sperm oil, cut 2	75% myristic acid	238.6	240.8	43.0	3.8
k	WCS sperm oil, cut 3	20% myristic, 76% palmitic	220.7	224.0	49.2	7.8
l*	WCS spermaceti acids	15% lauric, 32% myristic	215.1	224.0	43.4	11.0

\* Fractions giving satisfactory soaps when substituted for coconut oil acid in the regular 2-1-1 formulation.

TABLE V. EIGHT PER CENT GELS IN GASOLINE

Soap No.	Saturated Fatty Acid	Time at 77° F., Min.	
		Dispersion	Setting
IIIa	Approx. 50% lauric	7	17
IVa	More than 50% lauric	1 1/2	1
IVb	More than 50% lauric	1 1/2	5
IVc	More than 50% lauric	2	4
IVe	More than 50% lauric	1 1/2	2
IVf	More than 50% lauric	1 1/4	1 1/2
IVg	90% lauric	1 1/4	1 1/2
IVh	75% myristic	1 1/2	5
IVi	Lauric-myristic (47%)	1 1/4	3 1/2

The Napalm-type gels were developed to meet an urgent requirement for even a makeshift substitute for rubber gels. Actually, they surpass rubber gels in incendiary effectiveness; they are applicable for use in flame throwers whereas rubber gels are not; and the greater speed and simplicity of preparation of the gels have opened other fields of application. Although the new aluminum soap gels are very sensitive to the peptizing action of water and many other substances, fortunately they possess remarkable stability in storage, whereas rubber gels suffer syneresis on standing for a few months. Thus original samples of all the classes of gels described in this article have, in 1946, the same outward character they had when made up in the early months of 1942.

#### PRODUCTION AND USE

In concluding this account of early work on the problem, we wish to emphasize the fact that the research phase was but a small part of the effort required to carry Napalm successfully into large-scale production. The more extensive and difficult problem of making a satisfactory, stable, and uniform product was attacked and eventually solved through the combined efforts of several groups, both in the National Defense Research Committee and among manufacturers under contract with the Chemical Warfare Service. Some of the difficulties are summarized as follows by E. P. Stevenson, chief of Division 11 of NDRC: "In the course of manufacture an endless list of minor and major problems arose, reflected in the tendency toward enormous variations in quality between different manufacturers and between different lots made by the same manufacturer. There were also serious problems of aging requiring a great deal of research on the part of others."

The effective use of Napalm in weapons other than the M-69 and M-47 bombs is likewise to be credited to the foresight and industry of others. One spectacular application, of which we had not even dreamed, was to the flame thrower, characterized as follows by Secretary of War Patterson (2): "This 'dud' of World War I became one of the most potent weapons in Pacific operations. . . . It was Napalm which did this; the same thickened oil used in the incendiary bombs." With 4-6% gels of Napalm in gasoline it was possible "to throw streams of fire in a lancelike jet, with far greater range, velocity, and accuracy." Another unlooked-for adaptation, that was employed with success in the attack of island fortresses off the coast of France and then utilized on a large scale in the mopping-up operations in the Pacific, was the belly-tank fire bomb. Bombers flown overseas were supplied with extra gasoline stored in a belly tank fitted into the bomb bay in a manner permitting easy jettisoning when it was no longer needed. At first these tanks were discarded when the destination was reached but came into use as containers for huge fire bombs. At advance bases the tanks were loaded with gel prepared at the site from Napalm and aviation gasoline, and were transformed into completed bombs by the attachment of a white phosphorus-TNT burster tube similar to the one developed in this laboratory for use in the M-47 bomb. These belly tanks, usually released in a low-level attack, proved effective in driving the enemy out of caves and underground defensive installations, and in burning out whole areas held by stubbornly resisting Japanese troops.

The versatility of Napalm is illustrated by another incident. A small but efficient unit was desired for the starting of comfort fires—for example, by fliers forced down in jungle terrain. A celluloid cylinder filled with a Palmene or Napalm gel in Stoddard solvent (the "Harvard candle") met all the requirements and tests and was standardized as the M-1 fire starter. Then a variant model was required, made of two shallow stampings of 18-gage celluloid cemented together along a peripheral fin. The design was accepted, but the manufacturer encountered a serious obstacle in trying to inject viscous Napalm gel into the case through a 1/8-inch opening and leave the hole clean enough for cementing a cover disk over the hole. The problem was solved by placing Napalm powder in the case before the halves were cemented together and then running the solvent in through the narrow opening; a homogeneous gel was obtained merely by allowing the case to rest for a time on its flat side.

TABLE VI. SOAPS FROM COCONUT OIL ACID (2 PARTS), NAPHTHENIC ACID (1 PART), AND A SPECIAL ACID COMPONENT (1 PART)

Special Acid Component	Iodine No.	Evaluation of 13.5% Gasoline Gel
Cottonseed oil acid	90-105	Very thick, but short and crumbly
Soybean oil acid	122	Generally satisfactory
Corn oil acid	95-115	Very thick, but short and crumbly
Linseed oil acid	179-209	Good, stringy; stability questionable
Neo-Fat 3R	140	Excellent
Armour's animal acid	50-70	Good above -10° C., undergoes syneresis at -40°

According to an officer who inspected some of the Japanese areas devastated by the B-29 raids with M-69 bombs, a few of the more enterprising civilians salvaged a dud or two and made good use of the recovered Napalm for cooking and heating. Certain other uses of a more novel and scientific character are being investigated with promising results. It is too early as yet to know whether Napalm will find significant application in times of peace.

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