INSTITUTE OF PAPER CHEMISTRY
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GENERAL

INVESTIGATION OF SOLID LUBRICANTS AS AN AID IN CORRUGATING

Project 2696-10

Report Two

A Summary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 12, 1973

THE INSTITUTE OF PAPER CHEMISTRY
Appleton, Wisconsin 54911
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Project 2696-10

We are enclosing a copy of a report entitled "Investigation of Solid Lubricants as an Aid in Corrugating", Project 2696-10, Report Two, dated January 12, 1973. This work was concerned with the evaluation of various solid lubricants as antifriction agents to improve runnability and reduce high-lows.

The results indicate that substantial increases in runnability speed are obtained when the corrugating medium is treated with low molecular weight, low density non-emulsifiable polyethylene. High-lows are also reduced.

Based on an estimated consumption rate of 0.013-lb. polyethylene per 1000 ft.^{2} of A-flute board, the material costs would be about 0.36 cents per 1000 ft.^{2} of corrugated board of $0.18 per ton of corrugating medium. Thus the cost of treatment is relatively low, particularly since only medium rolls giving trouble on the single-facer need be treated. Lower application rates could probably be used. Further work would be required to determine the most effective rates of application.

It is also possible that blends of polyethylene with other materials would offer advantages. The best blending agent at this time appeared to be polyethylene glycol ester. A 2% blend of the ester and polyethylene improved high-lows to at least the same extent as the polyethylene alone. However, corrugating trials under more severe conditions would be required to properly determine the merits of blending agents.

We would appreciate receiving any comments you may have after you have had an opportunity to review the report.

Yours very truly,

R. C. McKee, Chairman
Container Section

GENERAL

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Appleton, Wisconsin

INVESTIGATION OF SOLID LUBRICANTS AS AN AID IN CORRUGATING

SUMMARY

This project was initiated for the purpose of evaluating the effectiveness of various solid lubricants as antifriction agents to improve runnability and high-lows of corrugating medium. A number of chemical companies were surveyed to obtain samples of materials having suitable lubricating properties, melting points, etc. These materials were "screened" using a "hot" friction test. For this purpose small amounts of the materials were abraded onto the surfaces of "standard" corrugating mediums. Using a steel foil heated to about 300-350°F. as the other surface, the kinetic coefficient of friction of the heated medium surface was determined and compared with the friction coefficient of the untreated medium. Corrugating trials were then carried out to evaluate the best candidate lubricants in terms of their effect on runnability and high-lows.

In general, the following results were obtained:

1. Substantial reductions in friction and improvements in runnability speed were obtained using low molecular weight, low-density nonemulsifiable polyethylenes (PE) as solid lubricants. The two materials of this type which gave the best results were as follows:

    (a) N-11 PE, Eastman Chemical Products

    (b) A-C-6 PE, Allied Chemical Co.

2. High-lows were reduced when the medium was treated with the N-11 PE. It is anticipated that similar results would be obtained with A-C-6.

3. The estimated rate of consumption was about 0.013 lb./1000 ft.^{2} of A-flute single-faced board. Thus, the cost of treatment is quite low, particularly in view of the fact that only medium rolls giving trouble on the single facer need be treated. Probably lower application rates could be used. Further work is recommended to determine the most effective rates of application.

4. A limited study was carried out to determine whether blends of PE with other materials would offer advantages. Several materials appear potentially promising as blending agents; however, further work would be needed to determine the best concentrations. The best blending agent at this time appeared to be a polyethylene glycol ester (dioleate) made by Emery Industries. A 2% blend of N-11 and dioleate improved runnability and high-lows to at least the same extent as N-11 alone; however, corrugating trials under more severe operating conditions would be required to properly determine the merits of blending agents.

INTRODUCTION

In the corrugating operation, the medium on the entrance side of the corrugating labyrinth travels faster than the peripheral speed of the flute tips of the corrugating rolls because of the draw necessary to allow it to be molded to the shape of the flutes. As the medium is drawn over each flute tip, friction induces a force in the medium which increases the tension. An analysis of this phenomenon shows that the tension stresses due to friction increase toward the center of the corrugating labyrinth. The increase in tension is a function of the coefficient of friction between the corrugating medium and heated corrugating roll surfaces. As one consequence, experiments have shown that it is possible to increase medium runnability speeds by applying small quantities of various additives to the medium surface which decrease the coefficient of friction. For example, McKee and Gander reported that application of a silicone mold release agent markedly increases the runnability speed (1).

In commercial operations, additives such as graphite and oil mists have been used. Schoo (2) in 1931 patented a system for applying paraffin or other lubricants to the corrugating rolls to give better formed flutes and reduce fracturing. As early as 1937 reference was made to the possibility of applying colloidal graphite to metal surfaces in the corrugator to reduce sticking of the medium to the corrugating rolls among other things (3). Also, Kane obtained a patent covering the application of an emulsifiable polyethylene to at least one surface of the web (4). His patent claims allow for application to the medium from a liquid mixture (aqueous emulsion or solvent system) or by passing the medium over solid blocks of the emulsifiable polyethylene. In addition, a patent by Morris and Norman (5) covers the use of stearin, paraffin wax as a lubricant.

More recent work has indicated that the runnability of "poor" mediums can be markedly improved by passing them over a solid bar made from an aliphatic organic derivative such as stearic acid. In view of the above, this study was initiated for the purpose of evaluating the relative effectiveness of various solid lubricants as antifriction agents to improve runnability and high-lows.

Various chemical companies were surveyed to obtain samples of materials having potential promise as lubricants. These materials were screened using a "hot" friction test. The more promising candidate materials were evaluated on the Institute's corrugator to obtain an evaluation of the improvement in runnability speed and high-lows associated with their use.

TEST PROCEDURES

FRICTION SCREENING TESTS

The "hot" friction tests were carried out by abrading small quantities of each candidate lubricant (prepared as a small cast block) onto the surfaces of two "standard" corrugating mediums. A steel-foil specimen heated to about 300-350°F. was used as the other friction surface. The kinetic coefficient of friction between the heated foil and "treated" medium surface was then measured. Four tests were made on each medium sample and the results for the two samples were composited. A fresh steel foil specimen was employed in testing each candidate lubricant.

The lubricant was abraded onto the surface of the medium by lightly weighting the cast block and drawing the medium test strip under the block. In most cases the abrasion process was carried out at room temperature (73°F.). However, in a few instances the abrasion was carried out after heating the lubricant block to 200°F.

In some instances the lubricant materials were received as liquids, pastes, or powders. Inasmuch as such materials could be potentially useful as blending additives, modified friction tests were carried out using such materials. Thin films of the paste or liquid materials were spread on Mylar film supported on a glass plate. The medium test strips were then drawn over the Mylar film so as to deposit a small amount of lubricant onto the medium surfaces. In the case of powders, small quantities were sifted onto the surface of the medium strip before carrying out the friction tests.

RUNNABILITY

The runnability trials were carried out on the Institute's corrugator using "normal" operating conditions except for web tension. The runnability of the untreated medium was evaluated either by (a) determining the maximum speed (up to 1000 f.p.m.) which could be employed without fracturing flutes using a web tension of 1.5 lb./in., or (b) by operating the corrugator at 100 f.p.m. and determining the maximum tension which could be employed without fracturing flutes.

The candidate lubricant was then applied to one side of the medium as it unwound from its parent roll and the runnability speed was determined. The web tension level was set at either (a) 1.5 lb./in. or (b) the level causing fracture at 100 f.p.m. When several different types of lubricants were being evaluated, the machine was operated at a slow speed for a short period of time after each run. Then the "control" runnability was redetermined before testing the next candidate lubricant.

Samples of the single-faced board were obtained at 100 f.p.m. for the untreated medium runs and at 100, 300, and 600 f.p.m. when lubricant was used.

FLUTE HEIGHT MEASUREMENTS

For each sample of single-faced board the heights of 101 consecutive flutes were measured. The measurements were made on a strip cut from the center region of the 12-inch wide board. The differences in height between adjacent flutes were calculated and averaged to give a measure of high-low flute formation.

DISCUSSION OF RESULTS

Table I shows the friction results obtained on the candidate materials submitted by the various chemical companies. Among the plastic materials (see Numbers 2-15) it appeared that the lowest friction coefficients were obtained with the low molecular weight polyethylenes such as N-10, N-11, N-12, A-C-6, A-C-8, and A-C-324 (see Numbers 2-6). Relative to the control, the friction coefficients were reduced by approximately 50% or more. It may be noted that none of these polyethylenes are of the emulsifiable type and, hence, are not believed to be covered by Kane's patent (4).

Blending MoS_2 with one of the polyethylenes did not have any great effect on the coefficient of friction (compare No. 7 and 9).

Of the three Eastman polyethylenes, N-11 has a slightly lower density than N-10 and N-12 and tended to give the lowest friction coefficient. Samples N-11 and N-12 have about the same molecular weight but N-11 with the lower density exhibited the lower friction coefficient. Comparing the Allied Chemical Samples A-C-6 and A-C-8, A-C-6 has the lower density and friction coefficient. These results suggest that lower friction coefficients tend to be obtained as the density is lowered.

Of the solid waxlike materials the lowest frictional coefficients were obtained with Albaplex (No. 16) and Oxazoline wax OWR-150E. The friction coefficients were only slightly greater than the coefficients obtained with the best polyethylenes (N-10, N-11).

Based on the results in Table I it was decided to conduct an evaluation on the corrugator of the following materials:

TABLE I

FRICTION SCREENING TESTS ON LUBRICANT MATERIALS

No.	Trade or Chemical Name	Manufacturer	Hot Coeff. of Friction 73°F. Ab. Temp.[a]	Hot Coeff. of Friction 200°F. Ab. Temp.[a]
1	Control		0.23	0.23
2	Low mol. wt., medium density PE, N-11	Eastman Chemical Products Co.	0.095	0.08
3	Low mol. wt., medium density PE, N-10	Eastman Chemical Products Co.	0.10	0.10
4	Low mol. wt., medium density PE, N-12	Eastman Chemical Products Co.	0.135	--
5	Low mol. wt., PE, A-C-6	Allied Chemical Co.	0.11	0.10
6	Low mol. wt., PE, A-C-8	Allied Chemical Co.	0.12	0.11
7	Low mol. wt., PE, A-C-324	Allied Chemical Co.	0.12	0.11
8	Blend – 70/30 mixture AC324 + H16H M.W. PE	--	0.13	0.10
9	Blend – AC 324 PE plus Molykote (MoS_2)	--	0.11	0.105
10	Reclaimed PE	Riverside Paper Co.	0.25	--[b]
11	Blend – Reclaimed PE plus Elvax 220	--	0.14	--[b]
12	Blend – Reclaimed PE plus Elvax 420	--	0.145	--[b]
13	Nylon bearing mat. (nylon + Molykote)	--	0.18	0.20
14	Polycarbonate	--	0.26	0.30
15	Polyvinyl chloride	--	0.24	0.28
16	Albaplex	Western Petrochemical Corp.	0.11	--
17	Oxazoline wax, OWR-150E	Comm. Solvents Corp.	0.12	--
18	Oxazoline wax, TS 970	Comm. Solvents Corp.	0.145	--
19	Oxazoline wax, TS 970AA	Comm. Solvents Corp.	0.16	--
20	Beeswax		0.14	--
21	Paraseal (paraffin wax)		0.28	--
22	Paraflint R.G.	Moore & Munger, Inc.	0.25	--
23	Armoslip HT	Armak Co.	0.205	--
24	Armoslip CPM	Armak Co.	0.23	--
25	BE square 190/195, Amber wax	Bareco Div., Petrolite Corp.	0.21	--
26	Polywax 2000	Bareco Div., Petrolite Corp.	0.20	--
27	Advawax 140 (fatty acid ester)	Cincinnati Milacron Chem. Inc.	0.15	--
28	Advawax 165 (refined paraffin lub.)	Cincinnati Milacron Chem. Inc.	0.195	--
29	Advawax 225 (hard fatty amide)	Cincinnati Milacron Chem. Inc.	0.19	--
30	Advawax 240	Cincinnati Milacron Chem. Inc.	0.16	--
31	Advawax 280	Cincinnati Milacron Chem. Inc.	0.17	--
32	Advawax 290	Cincinnati Milacron Chem. Inc.	0.175	--
33	Hard petrolatum	Ashland Oil Co.	0.245[c]	--
34	Tectyl TL152	Ashland Oil Co.	0.20[c]	--
35	Crude microwax	Ashland Oil Co.	0.19[c]	--
36	Wax D	Ashland Oil Co.	0.25[c]	--
37	BB66 (hydrogenated sperm oil replac.)	Keil Chemical Co.	0.20[c]	--
38	Base ML (methyl lardate)	Keil Chemical Co.	0.215[c]	--
39	Mobil set No. 3 (blended oil)	Mobil Oil Co.	0.175[c]	--
40	No. 239 coating additive	Norton Chemical Co.	0.135[c]	--
41	No. 2648 polyethylene glycol ester (dioleate)	Emery Industries, Inc.	0.195[c]	--
42	No. 2650 polyethylene glycol ester (monolaurate)	Emery Industries, Inc.	0.25[c]	--
43	No. 2652 polyethylene glycol ester (dilaurate)	Emery Industries, Inc.	0.235[c]	--
44	No. 3540 Butyl stearate ester	Emery Industries, Inc.	0.24[c]	--
45	No. 9058 Plastolein plasticizer (DOZ)	Emery Industries, Inc.	0.24[c]	--
46	F 157 wax (poly-stearoxy-siloxane)	Dow Corning	0.24[c]	--
47	No. 200 fluid (silicone)	Dow Corning	0.23[c]	--
48	Molykote 557 (spray)	Dow Corning	0.255[c]	--
49	Molykote Z (MoS_2) powder	Dow Corning	0.16[c]	--
50	Molykote 522 (teflon) powder	Dow Corning	0.175[c]	--

[a]Temperature at which lubricant was abraded onto medium.

[b]Material melted on hot plate.

[c]Received in form of liquid, paste, powder or aerosol.

1. N-11, low mol. wt. PE, Eastman Chemical Products
2. A-C-6, low mol. wt. PE, Allied Chemical Co.
3. Albaplex, Western Petrochemical Corp.
4. Oxazoline wax, Commercial Solvents Corp.

The results of the corrugator trials are shown in Table II. Very large improvements in runnability speed were obtained with all four of the candidate lubricants. There is an indication that the polyethylenes were slightly better than either the Albaplex or Oxazoline wax. Thus, the results confirmed that a solid lubricant may be used to increase runnability speed, and that nonemulsifiable polyethylenes are very effective for this purpose.

TABLE II

EFFECT OF SOLID LUBRICANTS ON RUNNABILITY

Run No.	Control	Runnability, f.p.m. Roll 1	Roll 2
1	Control	100	550
2	Treated with N-11, low mol. wt. PE	800	1000+
3	Control	100	550
4	Treated with A-C-6, low mol. wt. PE	800	1000+
5	Control	100	550
6	Treated with Albaplex	700	1000+
7	Control	100	--
8	Treated with Oxazoline wax, OWR-150E	700	--

Note: Plus sign indicates medium did not fracture at maximum speed (1000 f.p.m.).

The relative costs of the four materials are shown in Table III. The polyethylene materials have the lowest cost and would be favored on this basis.

TABLE III

MATERIAL COSTS

Material	Price per Pound, $
1. N-11	0.275
2. A-C-6	0.275
3. Albaplex	0.42
4. Oxazoline OWR-150E	1.05

Consumption estimates were not made during these runs; however, the amounts used were relatively small. If desirable, it should be possible, however, to further reduce the consumption by compounding with other materials to harden the cast blocks.

To determine if further improvements could be affected by blending the polyethylene with other materials, blends were prepared having the arbitrary proportions of 10 parts PE, 1 part candidate additive. Table IV summarizes the results. It appeared that one promising additive would be a polyethylene glycol ester of the dioleate type. The results for the polyethylene glycol esters also suggest that better results might be obtained with a monolaurate of lower molecular weight than tested herein; however, a sample could not be obtained in time to be evaluated in this study. The dioleate costs about 30 cents/pound. This is about the same as the polyethylene, hence, addition of dioleate as a blend additive would have only a slight effect on material costs.

TABLE IV

FRICTION SCREENING TESTS ON BLENDS OF N-11 POLYETHYLENE AND OTHER MATERIALS

(10 Parts PE, 1 part additive)

Trade or Chemical Name of Additive	Manufacturer	Coefficient of Friction
Control – no treatment		0.22
Control – treated with N-11 PE	Eastman Chemical Products Co.	0.095
Albaplex	Western Petrochemical Corp.	0.10
Oxazoline wax, OWR-150E	Comm. Solvents Corp.	0.135
Oxazoline wax, TS 970	Comm. Solvents Corp.	0.135
Oxazoline wax, TS 970AA	Comm. Solvents Corp.	0.145
Beeswax	--	0.125
Paraseal (paraffin wax)	--	0.135
Paraflint R.G.	Moore & Munger, Inc.	0.145
Armoslip HT	Armak Co.	0.135
Armoslip CPM	Armak Co.	0.16
BE square 190/195 amber wax	Petrolite Corp.	0.14
Polywax 2000	Petrolite Corp.	0.16
Advawax 140	Cincinnati Milacron Chem. Inc.	0.105
Advawax 165	Cincinnati Milacron Chem. Inc.	0.16
Advawax 225	Cincinnati Milacron Chem. Inc.	0.17
Advawax 240	Cincinnati Milacron Chem. Inc.	0.155
Advawax 280	Cincinnati Milacron Chem. Inc.	0.14
Advawax 290	Cincinnati Milacron Chem. Inc.	0.14
Hard petrolatum	Ashland Oil Co.	0.14
Tectyl TL 152	Ashland Oil Co.	0.14
Crude microwax	Ashland Oil Co.	0.135
Wax D	Ashland Oil Co.	0.095
BB 66	Keil Chemical Co.	0.16
Base ML	Keil Chemical Co.	0.145
Mobilset No. 3	Mobil Oil Co.	0.185
No. 239 Coating additive	Norton Chemical Co.	0.16
No. 2648 PE glycol ester (dioleate)	Emery Industries, Inc.	0.07
No. 2650 PE glycol ester (monolaurate)	Emery Industries, Inc.	0.125
No. 2652 PE glycol ester (dilaurate)	Emery Industries, Inc.	0.14
No. 2640 PE glycol ester (monostearate)	Emery Industries, Inc.	0.16
No. 3540 Butyl stearate ester	Emery Industries, Inc.	0.12
No. 9058 Plastolein plasticizer	Emery Industries, Inc.	0.15
Dow F157 wax	Dow Corning	0.18
No. 200 silicone	Dow Corning	0.105
Molykote Z (MoS_2)[a]	Dow Corning	0.145
Molykote 522 (teflon)[b]	Dow Corning	0.155
Seccolube S-400	Southeastern Chemical Corp.	0.19
Seccolube S-600	Southeastern Chemical Corp.	0.11
Zelec VN	E. I. du Pont	0.13
Ucon lubricant	Union Carbide	0.10
Stearic acid	J. T. Baker Chemical Co.	0.14
Emka lube F-11	Emkay Chemical Co.	0.14

[a] Compounded using ratio 60 parts PE, 1 part MoS_2.

[b] Compounded using ratio 18 parts PE, 1 part 522 powder.

It is possible that some of the other materials might be more effective at either higher or lower concentrations than were used in this study. Based on the results in Table IV it appears that further work involving other blend concentrations would be of interest for such additives as the following: Albaplex, Advawax 140, Ashland Oil wax D, No. 3540 butyl stearate ester, No. 200 silicone oil, Seccolube S-600, Zelec UN, and Ucon lubricant.

As mentioned previously, the most promising additive appeared to be the No. 2648 PE glycol ester (dioleate) made by Emery Industries, Inc. Accordingly, blends with Eastman N-11 PE were prepared having concentrations of 1, 2, 4, 8, 16, and 32% of the No. 2648 PE glycol ester. The friction results are summarized in Table V. As may be noted, the friction coefficients at all concentrations were somewhat higher than the result obtained with the one part to 10 part blend in Table IV. This is, perhaps, due to slight changes in the surfaces of the foil or medium samples from time-to-time. The friction coefficients in Table V were not markedly affected by concentration. However, the lowest coefficient was obtained at the 2% level.

TABLE V

FRICTION TESTS OF BLENDS OF N-11 PE
WITH NO. 2648 PE GLYCOL ESTER

Concentration of No. 2648, %	Coefficient of Friction
1	0.085
2	0.08
4	0.095
8	0.095
16	0.125
32	0.115

Additional runnability trials were carried out to compare the effectiveness of the plain PE (N-11) with that of a blend containing 98% N-11 and 2% of the No. 2648 ester. The results are shown in Table VI. For medium roll Numbers 16358/9, the untreated controls fractured at 100 f.p.m. using web tensions of 2.5 and 3.0 lb./in., respectively. When the mediums were treated on one side with either Eastman N-11 PE or the blend containing 2% No. 2648 PE glycol ester the runnability speeds were in excess of 1000 f.p.m. Thus, the lubricants markedly increased the runnability speed. However, it was not possible to determine whether the blend was superior to the plain PE because the maximum speed of 1000 f.p.m. was attained without fracture of the medium for both treatments. To evaluate the merits of blending agents, trials using more severe operating conditions on the corrugator would be required.

In the case of the third medium (16371) the runnability of the untreated medium was 100 f.p.m. at a very low tension level (<u>ca</u>. 0.3 lb./in.). It was difficult to control the web tension at this low level as speed was increased, although in one trial with lubricant N-11 satisfactory board was obtained at 300 f.p.m. at 0.5 lb./in. tension. Higher speeds could have been attained without fracture, tension control permitting. Because of the tension control problems, the speed was held at 100 f.p.m. and the tension was increased in 0.5 lb./in. increments to determine the tension which would cause fracture. With both lubricants, satisfactory board was produced at 1.0 lb./in. web tension as compared to the 0.3 lb./in. level for the untreated medium. Thus, even for this roll of very poor runnability the use of the lubricants improved runnability, probably to the point where the roll could be fabricated satisfactorily at least.

TABLE VI

RUNNABILITY RESULTS

Medium Roll No.	Treatment	Runnability Speed, f.p.m.	Runnability Tension, lb./in.
16358	Control	100	2.5 (3.0)[b]
	Treated with Eastmen N-11	1000+	3.0
	Treated with blend of N-11 and No. 2648 ester[a]	1000+	3.0
16359	Control	100	2.0 (2.5)[b]
	Treated with Eastman N-11	1000+	2.5
	Treated with blend of N-11 and No. 2648 ester[a]	1000+	2.5
16371	Control	100	ca. 0.3
	Treated with N-11	300+	0.5
	Treated with N-11	100	1.0
	Treated with blend of N-11 and 2648 ester[a]	100	1.0

[a]98% N-11 plus 2% polyethylene glycol ester No. 2648 (dioleate).

[b]Medium fractured at tension level shown in the parentheses.

Note: Plus sign indicates that medium did not fracture at indicated speed.

During these trials it was estimated that the rate of application was about 0.008-0.009 lb./1000 ft.^{2} of medium. This amounts to about 0.013 lb./1000 ft.^{2} of A-flute single-faced board. It is quite possible that smaller amounts could have been applied without markedly reducing the degree of improvement. Further trials are needed to determine the best effective rate of application. It can be seen that the material costs involved are relatively small. For example, taking the average rate of application in this study (0.013 lb./1000 ft.^{2} of A-flute single-faced board) the material costs for plain PE would be about 0.36 cents/1000 ft.^{2} or $0.18/ton. Because only those rolls which give trouble need be treated, the overall treatment costs should be relatively small on a yearly basis.

The high-low results obtained on the single-faced board samples are summarized in Table VII. On the average, the lubricants reduced high-lows at both the 100 and 300 f.p.m. speed relative to the untreated control at 100 f.p.m. Thus, it appears that the use of PE as a solid lubricant should result in better quality board from a high-low standpoint as well as increase runnability.

TABLE VII

EFFECT OF LUBRICANTS ON HIGH-LOWS

Treatment	Speed, f.p.m.	Av. Flute Height Diff., pt. Roll 16358	Av. Flute Height Diff., pt. Roll 16359	Composite Av.	Diff., %
Control	100	1.91	2.34	2.12	--
Treated with N-11	100	1.62	1.70	1.66	-22
	300	2.38	1.68	2.03	-4
	600	3.34	3.20	3.27	+54
Treated with N-11 blend[a]	100	1.77	1.63	1.70	-20
	300	1.76	1.54	1.65	-22
	600	2.06	2.69	2.38	+12

[a]98% N-11 PE, 2% No. 2648 PE glycol ester.

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