COLD TREATING OF OILFIELD EMULSIONS

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INTRODUCTION

In the early years of emulsion treating in the oil field, heat and settling were the only major factors employed. Large open pits frequently provided the settling time and the sun contributed some heat. "Sunning" was a common practice. Some producers employed crude-oil fired retorts and stills to reduce the water content of crude. Large boilers were frequently used to heat tanks of emulsion to facilitate settling of water and emulsion. The large amounts of unresolved emulsion from such operations were usually burned as a means of disposal.

With the advent of chemical and electrical treatment, the above procedures were gradually replaced. The use of some heat has continued to the present day but treating temperatures have gradually been reduced with many treating plants operating at ambient temperature. Required settling time has also been drastically reduced over the years.

For the most part, the energy required to heat crude as part of the treating process, has been supplied by products produced on the lease so has not been recognized as an expense. Losses in crude gravity and volume, sustained as a result of heating, were judged to be insignificant and difficult to measure and had little or no impact on the value or volume of product sold.

In past years, heat may have been a low cost factor in treating. Today, with the shortage of fuel and its increased cost, the economics of the use of heat is worth reevaluating.

Before assessing the possibility of reducing heat in oil treating, however, a review of emulsification and oil treating is in order to better understand the role of heat.

Emulsification

A regular oilfield emulsion is a stable dispersion of produced water in produced crude oil. Oil and water alone would not form this stable dispersion so it is necessary for a third component to be present. This third component is called the emulsifier and is always present in a crude oil system. It can be any one or a combination of surface-active materials such as asphaltines, resins, organic acids, salts, silt, clay, paraffin and many others. These materials have an attraction for water/oil interfaces.

As water in the crude oil is mechanically broken up into small droplets by passing through pumps, chokes, or in any way subjected to severe agitation or pressures, the emulsifier migrates to the interface, coats it, and thus stabilizes the droplet at that size. A water droplet stabilized in this manner acts like a solid sphere and its rate of settling in oil can be predicted by Stokes Law. (See Appendix.) This law states in general, that the rate of fall of a solid sphere in a liquid is influenced by the following factors:

1. Linearly by the viscosity of the crude oil. As the oil gets thinner, the water droplet falls faster.
2. Linearly by the difference in the specific gravity of the two materials, oil and water. The heavier the water relative to the oil, the faster the water droplet falls.
3. By the square of the radius of the water droplet. The larger the droplet, the faster it will fall.

Heat influences the rate of settling of water droplets by reducing the viscosity of the oil and increasing the difference in specific gravity between the water and oil.

For instance, with a typical 35° API gravity crude, increasing temperature from 100°F to 140°F would speed up the settling rate by about 40% due to viscosity change and an additional 34% due to change in gravity difference. If settling required 12 hours at 100°F, this would be reduced to a little less than 7 hours at 140°F.

Heat can also influence water droplet size, particularly where the emulsifier can be melted or dissolved by heat and thereby removed from the interface.

Chemical composition and agitation are the primary factors in increasing the size of water droplets. Agitation helps distribute the chemical in the emulsion and after the emulsion is broken, additonal agitation promotes coalescence or growth of water droplets. Demulsifiers in current use are strongly surface-active and have the ability (with a minimum of agitation) to distribute themselves throughout the emulsion and bring water droplets together for ready coalescence. Increasing the size of the water droplet has a dramatic effect on reducing settling time. For instance, if a droplet takes 12 hours to settle, just doubling its size would reduce settling time to 3 hours. In actual emulsion treating, water droplets are regularly increased in size from 100 to 1000 times their stable emulsified size.

Chemicals also have the ability to disperse solid materials which accumulate at the interface and therefore remove them as an emulsion stabilizer.

EMULSION TREATING

The regular emulsion-treating program incorporates four basic factors: chemical, agitation, heat, and settling time. A certain amount of each of these working together yield treated oil. Like an equation or scale, the treating factors on one side are in balance with the treated oil on the other. Reducing the amount of one or more of the treating factors will destroy the balance and will therefore yield undertreated oil. However, if when one of the treating factors is reduced, one or more of the others is increased adequately, the balance can be maintained and treated oil can be produced. A review of the functioning of each of these factors is important in determining the limits within which it may be fluctuated.

Chemical

The chemical demulsifier performs several different functions in doing its job adequately.

1. It must be highly surface-active in order to rapidly get to the interface. It must also compete for surface space with the large accumulation of emulsifier which has had a head start in collecting at the interface.
2. A portion of the demulsifier imparts an attractive force between small emulsifier water particles so they tend to flocculate or form into bunches.
3. Another portion of the demulsifier acts on the emulsifier film to rupture it and allow coalescence of water droplets.
4. Where solids contribute to emulsion stability, the demulsifier must be able to disperse them in one or the other of the liquids.

These properties of the demulsifier are balanced to meet the demands of the crude to be treated. In general, the higher the concentration of demulsifiers, the faster the treating. The higher concentration results in great coverage of interface area and more rapid coalescence. In certain instances, a high concentration of the flocculation portion of the demulsifier, being very fast acting, will join large numbers of emulsified droplets and pack them so tightly together that the coalescing part of the compound is "blocked out" from getting to the surface and doing its job. In such situations, it is necessary to use a demulsifier which has lower flocculation power and higher coalescing power. In most cases, it is possible to increase the demulsifier sufficiently to offset reductions in the other treating factors and produce treated oil.

Agitation

After the chemical is added to the emulsion, agitation distributes it evenly; and after the emulsion is broken, additional agitation promotes coalescence of growth of water droplets for increased rate of settling. In some instances, continued agitation is helpful but in most systems this is not the case. Field use of baffled mixing chambers, atomized injection techniques and additional piping has shown little if any, improvement in treating.

Heat

Heating crude oil influences the treating process in several ways:

1. It makes the oil thinner and therefore water droplets are able to fall faster.
2. It increases the difference in weight between water and oil so the water droplets falls faster.

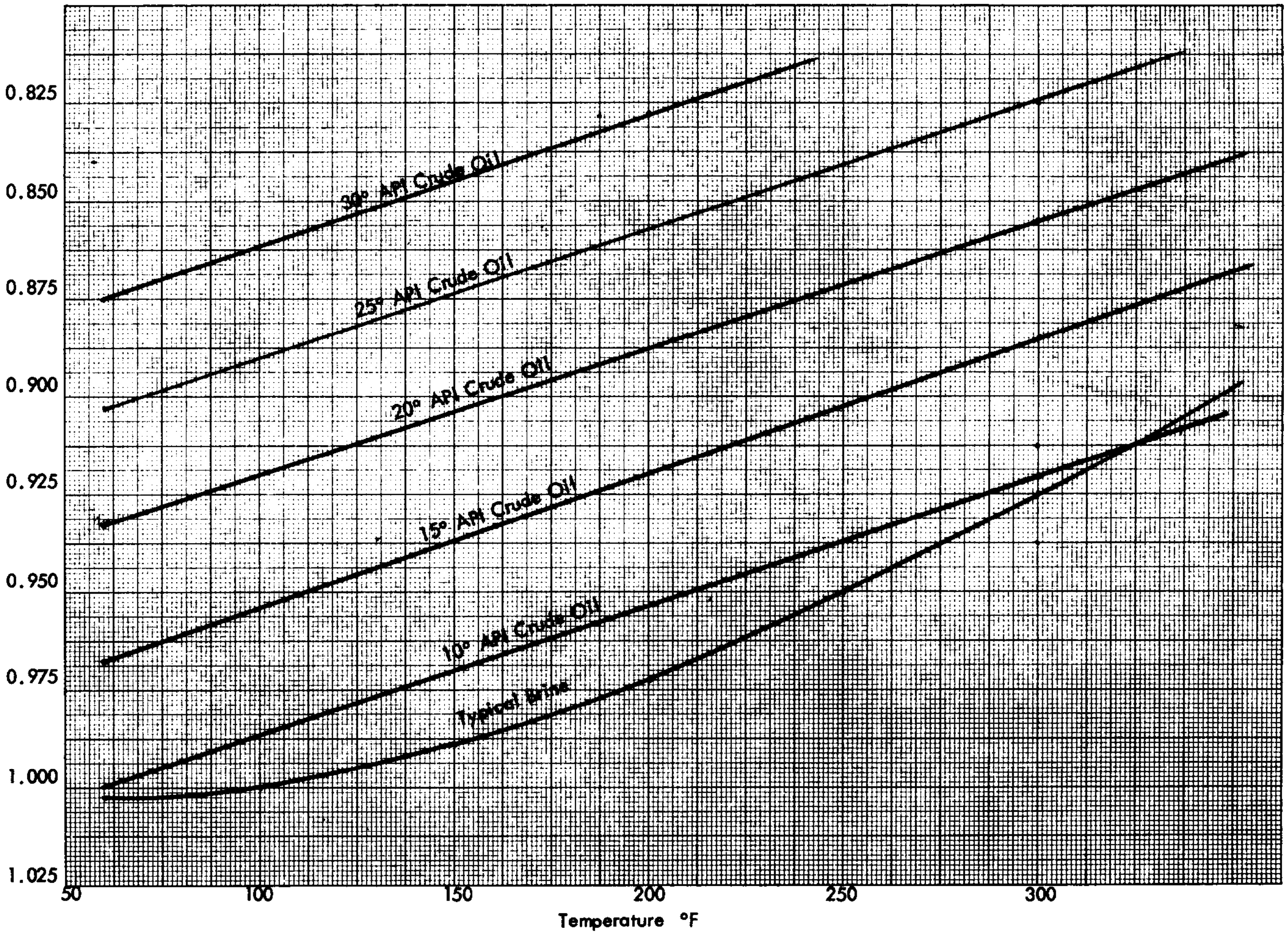

FIG. 1—CHANGE IN SPECIFIC GRAVITY WITH CHANGE IN TEMPERATURE

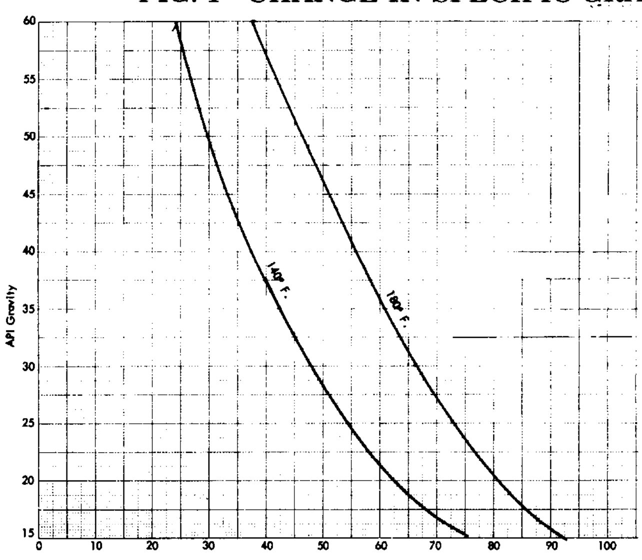

FIG. 2—CHANGE IN SETTING TIME WITH INCREASED TEMPERATURE COMPARED TO THAT AT 100°F

See Fig. 1.

Figure 2 shows the reduction in settling time on different gravity crudes by heating from 100°F to 140°F and 180°F.

3. It melts and solubilizes solids such as paraffin which may be acting to stabilize the emulsion, thereby removing them from the interface.
4. It improves the mobility of demulsifier and water droplets, thus improving the rate of emulsion breaking.

Settling Time

Sufficient volume capacity must be provided to allow the water to fall out of the oil. As already depicted, the thicker the crude and the smaller the water droplet, the longer the settling time and consequently, more capacity required to provide this time. Increasing settling time can offset reductions in other treating factors.

Both theoretical knowledge and field experience prove that reductions in treating temperature can be realized when chemical and/or settling time is increased.

ECONOMICS

The use of heat in treating contributes several advantages but at a loss of profits due to unnecessary costs. Those costs are reflected in:

1. Fuel for heat
2. Lower volume produced oil
3. Lower gravity produced oil
4. Equipment failure

In the past, fuel for heating was provided by the produced gas and little or no value was placed on it. Today with a market for everything produced, the heater fuel has a definite value. For example, with certain assumptions, this value can be calculated.

Assume:

Fuel gas@ $0.42/MCF

150 BTU/bbl oil/°F.
400 BTU/bbl water/°F.
30% water-cut emulsion
50% heating efficiency
1100 BTU gas
60°F temperature rise

Then the cost of fuel gas would be $1.47 per 100 bbl treated oil.

As oil is heated, vapor pressure increases and light ends evaporate, thus reducing volume and gravity. The percentage loss is quite variable and subject to such influences as crude gravity and composition, temperature change, treater pressure, heat exchange efficiency, time and other factors. Field evaluation of three leases producing broadly differing gravity crudes showed the following: With 60°F temperature rise and 25 psig treater pressure, volume of sale oil was reduced an average of 2.9%. At a value of $5.25/bbl this results in a loss of $15.23/100 bbl. At $0.42/MCF, the value of the increased gas produced at the higher temperature averaged $1.83/100 bbl. This yields a net loss of $13.40/100 bbl as a result of volume loss at the higher temperature.

Loss of light ends results in a decrease in gravity. Since much crude is sold on a sliding scale with the posted price decreasing as the gravity decreases, the profit loss may be appreciable. Figure 3 shows the relationship of volume and gravity losses for different gravity crudes. A 2.9% volume loss on a 30° API crude shows a gravity loss of 1.3° API. At a $0.02 penalty per 1.0° API gravity drop, this amounts to a profit loss of $2.60/100 bbl.

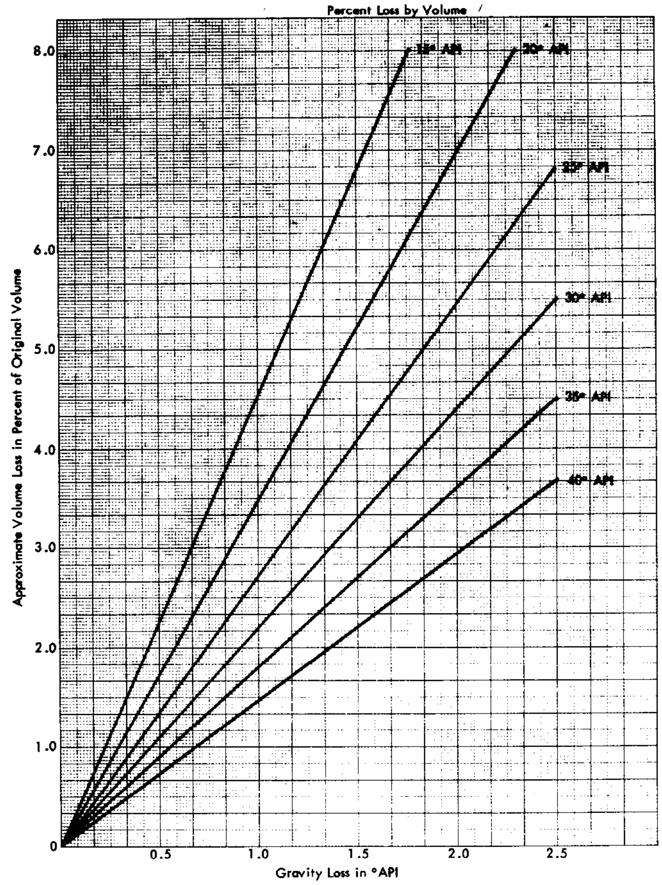

FIG. 3—GRAVITY LOSS IN °API VS. PERCENT LOSS BY VOLUME

Increased heat results in increased scaling and more frequent burnout of fire tubes. While this constitutes a definite operating expense or potential profit loss, it will fluctuate so broadly that no attempt will be made here to affix a dollar value.

Costs attributable to heat in the above examples total $17.47/100 bbl plus equipment maintenance costs.

Experience shows that with most oilfield emulsions, some if not all of the added heat can be replaced by chemical. The amount of increased chemical will fluctuate considerably depending on the crude and the temperature range involved. However, as a rough guideline, assume one-third more chemical for each 20° drop in temperature between 180°F and 120°F, two-thirds more chemical for each 20° drop between 120°F and 80°F and double the amount of chemical for each 20° drop below 80°F. Relating to the previously used examples of 60° heat reduction from 140°F to 80°F, about four times as much chemical would be required. If treatment required two quarts per 100 bbl at 140°F, about eight quarts would be required at 80°F or an increase of 1.5 gal. At a typical cost of $4.00/gal. for chemical, the increased cost would be $6.00/100 bbl. Compared to the previously calculated heat cost of $17.47, the net saving by reducing heat would be $11.47/100 bbl.

Reducing heat can be a good way to sell more oil and increase profits. As a practical approach to reducing heat, it is recommended that this be done 20° at a time. This allows for adjustments as needed to prevent possible accumulation of bad oil.

For many producers, the cold treatment has meant changing operating expenses into net operating profits. It's worth a try.

APPENDIX

STOKES LAW

Stokes Law equates the rate of fall of a small sphere through a viscous fluid and states that when this sphere is under the influence of gravity, it obtains a constant velocity which is given by the following equation.

$$V = \frac{2gr^2 (d_1 - d_2)}{9n_2}$$

where: g = 980 cm/sec
d_1 = density of dispersed phase (water) in g/cc
d_2 = density of continuous phase (oil) in g/cc
n_2 = viscosity in poises of continuous phase (oil) at settling temperature
r = radius of dispersed phase (water droplet) in cm.
V = rate of fall of water in cm/sec. If negative, the dispersed phase will rise.

A second equation by Rybczynski and Hadamard more accurately describes the rate of fall of oil field waters in crude oil. Stokes Law was modified to yield the following:

$$V = \frac{2gr^2(d_1 - d_2)}{3n_2} \left(\frac{n_1 + n_2}{3n_1 + 2n_2} \right)$$

In this formula the viscosity of the dispersed phase(n_1) is taken into consideration where Stokes Law applies only when the dispersed phase is a rigid sphere. Settling rates by this formula will be from 20 to 50% greater than those obtained by Stokes Law. The kinematic viscosity of water being 1 cs.

Additional work was done later that indicated the presence of an adsorbed interfacial film may lead to a high interfacial viscosity and the droplets would act like solid particles, thus following Stokes Law.

With the emulsions being stabilized by asphaltines and other surface active or inorganic materials, the rate of fall more than likely follows Stokes Law initially, and later as this film is ruptured and changed by the addition of a surface active demulsifier, the rate of fall is better described by Rybczynski and Hadamard's equation.

In order to simplify the discussion, calculations and tables, Stokes Law has been used to evaluate the factors that affect the rate of fall, keeping in mind that the rate of fall will be greater as the water droplet becomes less influenced by the emulsifying interfacial film.

Table 1 summarizes the API gravity and Saybolt viscosities for 616 oil fields in the United States. From these results, Table 2, consisting of typical physical properties, was generated.

EXPLANATION OF TABLE 2

Specific Gravity—In gm/cc is constant for a given API gravity and can be taken directly from Table 3.

Typical Saybolt Viscosity—The normal Saybolt viscosity at 100°F in seconds taken from 616 oil fields was used. While this viscosity will vary depending on the amount of paraffin and asphaltines, for purposes of this discussion, the data has been considered typical.

Absolute Viscosity at 100°F (Poise)—Absolute viscosity (poises) is equal to the kinematic viscosity (Stokes) times the specific gravity. One centistoke equals one one-hundredth of a stoke.

Kinematic viscosity (Stokes) = Ct-B/t where t is the observed time in seconds. B and C are constants which are dependent on the viscosimeter used. A table, relating these constants to the viscosimeter, is shown on the next page.

Viscosities at 140°F and 180°F were estimated by using ASTM viscosity-temperature charts.

Petroleum emulsions are generally in the 3 to 10 microns range (1 micron = 0.0001 cm). The use of a demulsifier destroys the emulsion by allowing coalescence to occur. As can be seen by Table 4, it is this coalescence of the water droplets that allows resolution of petroleum emulsions within a given time.

Viscosimeter	Range of Flow Time	B	C
Saybolt Universal	32-100	1.95	0.00226
	> 100	1.35	0.00220
Saybolt Furol	25-40	1.84	0.0224
	> 40	0.60	0.0216
Redwood No. 1	34-100	1.79	0.00260
	> 100	0.50	0.00247
Redwood Admiralty	ALL	20.06	0.027
Engler	ALL	3.74	0.00147

Table 4 lists the rate of fall for various water droplet sizes at three temperatures for the range of gravities from 14 to 60. Stokes Law was used in determining the rate of fall.

If only Stokes Law governed the rate of fall of the dispersed phase (water) as shown in Table 4, the additional settling times would prohibit the lowering of temperatures. For higher API gravity crudes, the additional time required would be 15-50% greater for a drop in temperature from 180° to 140°. In order to lower the temperature even further to 100°F, it would require 30-100% more settling time than at 180°F. For lower API gravity crudes, these two percentages increase to 100-300% for temperature decreases from 180° to 140°F and 400-1000% for decreases from 180° to 100°F.

Fortunately there are five other factors listed below which will aid in coalescence thus allowing the treatment of crude oil at lower temperatures.

1. Stokes Law applies to static systems whereas oilfield treaters contain horizontal and/or vertical movement. It is this movement that encourages coalescence of water droplets yielding greater settling rates than in Table 4.
2. The use of a water leg in treaters not only removes the free water but aids in coalescence and increased water drop size.
3. As the temperature is lowered the rate of fall of the water droplet will initially be slower. As this droplet falls it has a more effective sweeping action thus combining with smaller droplets that would have previously been left in the dispersed phase to fall on their own.
4. At lower temperatures the use of increased agitation prior to the treating vessel will allow better dispersion of the chemical. In addition, more effective coalescence will result in larger water droplets.
5. The use of increased chemical concentrations or a different chemical may yield more interaction between emulsion droplets and improve coalescence.

TABLE 1—SUMMARY OF 616 U.S. OIL FIELDS

Gravity API	No. of Fields	Saybolt Viscosity @ 100°F., Seconds Max	Min	Normal
61.5	1	--	--	33
55.9	1	--	--	32
54.9	1	--	--	34
54.7	1	--	--	32
53.7	1	--	--	33
53.2	1	--	--	33
52.0	3	54	34	34
51.1	1	--	--	35
50.1	1	--	--	36
49.2	2	47	35	35
48.5	1	--	--	35
48.1	1	--	--	33
46.5	2	43	34	35
46.3	1	--	--	35
46.0	2	35	35	35
45.8	2	58	34	35
45.6	5	40	33	35
45.4	3	35	34	35
45.2	1	--	--	37
44.9	1	--	--	38
44.7	4	40	36	37
44.5	4	39	33	36
44.3	3	38	36	37
44.1	3	38	33	37
43.8	1	--	--	39
43.6	3	40	32	37
43.4	1	--	--	39
43.2	2	35	35	35
43.0	6	42	32	34
42.8	2	36	36	36
42.6	2	41	35	37
42.5	1	--	--	39
42.3	2	38	37	38
42.1	11	42	35	38
41.9	4	44	34	38
41.7	8	39	34	38
41.5	5	41	33	40
41.3	9	46	35	38
41.1	10	44	34	38
40.9	5	41	34	38
40.6	3	39	35	36
40.5	1	--	--	35
40.4	6	47	37	39
40.2	6	65	37	39
40.0	3	39	35	39
39.8	6	132	35	39
39.6	9	43	35	40
39.4	7	43	35	40
39.2	9	46	36	41
39.0	5	64	33	41
38.8	8	46	35	41
38.6	7	44	35	41
38.4	4	40	35	39
38.2	11	55	31	41
38.0	10	48	38	43
37.8	6	47	39	43
37.6	8	47	35	43
37.4	10	46	40	43
37.2	9	47	38	42
37.0	6	49	33	43
36.8	9	46	40	43
36.6	7	49	37	43
36.4	10	52	35	44
36.2	9	50	41	46
36.0	9	75	40	44
35.8	10	66	42	47
35.6	9	48	41	44
35.4	6	47	41	45
35.2	8	51	41	44
35.0	11	100	40	48
34.8	8	56	39	46
34.6	10	52	37	45
34.4	7	55	37	46
34.2	5	48	43	44
34.0	11	52	42	47
33.8	8	57	42	48
33.6	7	56	43	48
33.4	3	71	49	49
33.2	7	56	42	48
33.0	3	48	44	48
32.8	4	52	43	47
32.7	3	56	45	48
32.5	6	74	45	56
32.3	8	74	45	50
32.1	3	65	51	51
31.9	7	61	44	50
31.7	3	52	45	51
31.5	5	67	41	52
31.3	4	56	45	48
31.1	6	74	39	55
31.0	4	85	55	57
30.8	2	61	49	59
30.6	4	73	46	61
30.4	4	79	51	61
30.2	3	67	54	59
30.0	3	76	54	57
29.9	6	73	46	59
29.8	1	--	--	49
29.7	6	62	49	59
29.5	1	--	--	72
29.3	4	105	62	63
29.1	2	87	78	78
28.9	2	110	64	65
28.8	4	69	44	67
28.7	2	73	57	68
28.6	7	105	47	63
28.4	1	--	--	59
28.2	5	105	66	72
28.0	2	115	65	70
27.9	1	--	--	135
27.7	1	--	--	56
27.5	1	--	--	66
27.3	3	130	68	72
27.1	4	91	58	76
27.0	4	131	55	80
26.8	4	135	57	82
26.3	2	242	76	85
26.1	2	93	85	90
25.9	2	80	54	80
25.7	4	100	93	95
25.4	2	135	89	105
25.2	2	115	62	110
24.7	1	--	--	78
24.5	1	--	--	145
24.3	1	--	--	140
24.2	3	175	36	140
24.0	1	--	--	135
23.8	4	165	140	140
23.7	2	66	60	66
23.5	1	--	--	84
23.3	3	360	220	220
23.1	3	580	165	180
23.0	1	--	--	170
22.8	1	--	--	135
22.6	5	230	135	220
22.5	1	--	--	220
22.1		190	124	190
22.0	2	230	180	230
21.6	1	--	--	82
21.5	1	--	--	250
21.0	2	550	91	300
20.7	2	340	320	320
20.5	1	--	--	520
20.2	4	500	96	400
19.8	1	--	--	410
19.0	1	--	--	1230
18.9	1	--	--	540
18.1	1	--	--	680
17.5	2	3000	1750	1750
17.3	1	--	--	765
17.1	1	--	--	1480
16.0	1	--	--	1900
15.9	1	--	--	1420
15.0	1	--	--	2440
14.8	2	>6000	5100	5100
14.7	1	--	--	>6000
14.5	1	--	--	2860
13.8	1	--	--	>6000
13.6	1	--	--	>6000
13.3	1	--	--	>6000
12.7	1	--	--	>6000
12.6	1	--	--	>6000
11.7	1	--	--	>6000
11.1	1	--	--	>6000

TABLE 2—TYPICAL PHYSICAL PROPERTIES

Gravity API	Specific Gravity gm/cm^3	Typical Saybolt Vis @ 100°F., Sec	Typical Vis @ 100°F. Poise	Calculated Vis @ 140°F. Poise	Calculated Vis @ 180°F Poise
60	0.7389	32	0.0084	0.0064	0.0052
59	0.7428	32	0.0085	0.0065	0.0052
58	0.7467	32	0.0085	0.0065	0.0052
57	0.7507	32	0.0085	0.0065	0.0053
56	0.7547	32	0.0086	0.0066	0.0053
55	0.7587	32	0.0086	0.0066	0.0053
54	0.7628	33	0.0118	0.0088	0.0069
53	0.7669	33	0.0119	0.0088	0.0069
52	0.7711	34	0.0150	0.0108	0.0085
51	0.7753	35	0.0181	0.0122	0.0091
50	0.7796	35	0.0182	0.0122	0.0092
49	0.7839	35	0.0183	0.0123	0.0093
48	0.7883	35	0.0184	0.0124	0.0093
47	0.7927	35	0.0185	0.0124	0.0094
46	0.7972	36	0.0217	0.0140	0.0102
45	0.8017	37	0.0248	0.0160	0.0112
44	0.8063	37	0.0249	0.0161	0.0113
43	0.8109	37	0.0251	0.0162	0.0114
42	0.8155	38	0.0282	0.0174	0.0122
41	0.8203	38	0.0283	0.0175	0.0123
40	0.8251	39	0.0315	0.0200	0.0134
39	0.8299	41	0.0374	0.0238	0.0154
38	0.8348	42	0.0405	0.0243	0.0162
37	0.8398	43	0.0435	0.0259	0.0175
36	0.8448	44	0.0466	0.0283	0.0188
35	0.8498	45	0.0496	0.0297	0.0196
34	0.8550	46	0.0526	0.0310	0.0205
33	0.8602	48	0.0584	0.0335	0.0217
32	0.8654	50	0.0640	0.0363	0.0234
31	0.8708	55	0.0774	0.0403	0.0251
30	0.8762	59	0.0879	0.0473	0.0298
29	0.8816	65	0.1030	0.0528	0.0322
28	0.8871	70	0.1156	0.0577	0.0355
27	0.8927	80	0.1396	0.0705	0.0411
26	0.8984	90	0.1633	0.0800	0.0449
25	0.9042	110	0.2077	0.0904	0.0524
24	0.9100	140	0.2715	0.1183	0.0632
23	0.9159	180	0.3558	0.1392	0.0724
22	0.9218	220	0.4405	0.1705	0.0825
21	0.9279	300	0.6082	0.1902	0.0928
20	0.9340	400	0.8188	0.2709	0.1205
19	0.9402	600	1.2389	0.4071	0.1636
18	0.9465	800	1.6642	0.4941	0.1959
17	0.9529	1200	2.5146	0.6251	0.2516
16	0.9593	1800	3.7981	1.0523	0.3942
15	0.9659	2400	5.0994	1.2731	0.4617
14	0.9725	6000	12.8368	2.7804	0.8529

TABLE 3—SPECIFIC GRAVITY CORRESPONDING TO DEGREES A.P.I.

Degrees API	Tenths of Degrees 0	1	2	3	4	5	6	7	8	9
60	.7389	.7385	.7381	.7377	.7374	.7370	.7366	.7362	.7358	.7354
59	.7428	.7424	.7420	.7416	.7412	.7408	.7405	.7401	.7397	.7393
58	.7467	.7463	.7459	.7455	.7451	.7447	.7443	.7440	.7436	.7432
57	.7507	.7503	.7499	.7495	.7491	.7487	.7483	.7479	.7475	.7471
56	.7547	.7543	.7539	.7535	.7531	.7527	.7523	.7519	.7515	.7511
55	.7587	.7583	.7579	.7575	.7571	.7567	.7563	.7559	.7555	.7551
54	.7628	.7624	.7620	.7616	.7612	.7608	.7603	.7599	.7595	.7591
53	.7669	.7665	.7661	.7657	.7653	.7649	.7645	.7640	.7636	.7632
52	.7711	.7707	.7703	.7699	.7694	.7690	.7686	.7682	.7678	.7674
51	.7753	.7749	.7745	.7741	.7736	.7732	.7728	.7724	.7720	.7715
50	.7796	.7792	.7788	.7783	.7779	.7775	.7770	.7766	.7762	.7758
49	.7839	.7835	.7831	.7826	.7822	.7818	.7813	.7809	.7805	.7800
48	.7883	.7879	.7874	.7870	.7865	.7861	.7857	.7852	.7848	.7844
47	.7927	.7923	.7918	.7914	.7909	.7905	.7901	.7896	.7892	.7887
46	.7972	.7967	.7963	.7958	.7954	.7949	.7945	.7941	.7936	.7932
45	.8017	.8012	.8008	.8003	.7999	.7994	.7990	.7985	.7981	.7976
44	.8063	.8058	.8054	.8049	.8044	.8040	.8035	.8031	.8026	.8022
43	.8109	.8104	.8100	.8095	.8090	.8086	.8081	.8076	.8072	.8067
42	.8155	.8151	.8146	.8142	.8137	.8132	.8128	.8123	.8118	.8114
41	.8203	.8198	.8193	.8189	.8184	.8179	.8174	.8170	.8165	.8160
40	.8251	.8246	.8241	.8236	.8232	.8227	.8222	.8217	.8212	.8208
39	.8299	.8294	.8289	.8285	.8280	.8275	.8270	.8265	.8260	.8256
38	.8348	.8343	.8338	.8333	.8328	.8324	.8319	.8314	.8309	.8304
37	.8398	.8393	.8388	.8383	.8378	.8373	.8368	.8363	.8358	.8353
36	.8448	.8443	.8438	.8433	.8428	.8423	.8418	.8413	.8408	.8403
35	.8498	.8493	.8488	.8483	.8478	.8473	.8468	.8463	.8458	.8453
34	.8550	.8545	.8540	.8534	.8529	.8524	.8519	.8514	.8509	.8504
33	.8602	.8597	.8591	.8586	.8581	.8576	.8571	.8565	.8560	.8555
32	.8654	.8649	.8644	.8639	.8633	.8628	.8623	.8618	.8612	.8607
31	.8708	.8702	.8697	.8692	.8686	.8681	.8676	.8670	.8665	.8660
30	.8762	.8756	.8751	.8745	.8740	.8735	.8729	.8724	.8718	.8713
29	.8816	.8811	.8805	.8800	.8794	.8789	.8783	.8778	.8772	.8767
28	.8871	.8866	.8860	.8855	.8849	.8844	.8838	.8833	.8827	.8822
27	.8927	.8922	.8916	.8911	.8905	.8899	.8894	.8888	.8883	.8877
26	.8984	.8978	.8973	.8967	.8961	.8956	.8950	.8944	.8939	.8933
25	.9042	.9036	.9030	.9024	.9018	.9013	.9007	.9001	.8996	.8990
24	.9100	.9094	.9088	.9082	.9076	.9071	.9065	.9059	.9053	.9047
23	.9159	.9153	.9147	.9141	.9135	.9129	.9123	.9117	.9111	.9106
22	.9218	.9212	.9206	.9200	.9194	.9188	.9182	.9176	.9170	.9165
21	.9279	.9273	.9267	.9260	.9254	.9248	.9242	.9236	.9230	.9224
20	.9340	.9334	.9328	.9321	.9315	.9309	.9303	.9297	.9291	.9285
19	.9402	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346
18	.9465	.9459	.9452	.9446	.9440	.9433	.9427	.9421	.9415	.9408
17	.9529	.9522	.9516	.9509	.9503	.9497	.9490	.9484	.9478	.9471
16	.9593	.9587	.9580	.9574	.9567	.9561	.9554	.9548	.9541	.9535
15	.9659	.9652	.9646	.9639	.9632	.9626	.9619	.9613	.9606	.9600
14	.9725	.9718	.9712	.9705	.9698	.9692	.9685	.9679	.9672	.9665

TABLE 4—SETTLING TIME IN INCHES PER HOUR

100 Micron Water Drop Size			200 Micron Water Drop Size			400 Micron Water Drop Size			1000 Micron Water Drop Size			2000 Micron Water Drop Size		
100°F	140°F	180°F	100°F	140°F	180°F	100°F	140°F.	180°F	100°F	140°F	180°F	100°F	140°F	180°F
23.98	31.48	38.74	95.92	125.90	154.95	383.7	503.7	619.9	2398	3148	3874	9,594	12,592	15,498
23.35	30.53	38.16	93.38	122.11	152.63	373.6	488.5	610.6	2335	3053	3816	9,340	12,213	15,267
22.97	30.07	37.58	91.96	120.26	150.32	367.9	481.1	601.4	2299	3007	3759	9,198	12,028	15,053
22.63	29.59	36.29	90.51	118.36	145.15	362.1	473.5	580.7	2263	2959	3629	9,053	11,838	14,518
22.01	28.68	35.71	88.02	114.69	142.83	352.1	458.9	571.4	2201	2868	3571	8,804	11,472	14,286
21.65	28.21	35.13	86.58	112.82	140.50	346.4	451.4	562.1	2165	2821	3513	8,660	11,285	14,053
15.51	20.80	26.52	62.03	83.18	106.08	248.2	332.8	424.4	1551	2080	2652	6,205	8,320	10,610
15.11	20.44	26.07	60.45	81.74	104.25	241.8	327.0	417.1	1511	2044	2607	6,046	8,176	10,427
11.77	16.35	20.78	47.09	65.40	83.10	188.4	261.7	332.5	1177	1635	2078	4,710	6,542	8,312
9.58	14.21	19.05	38.31	56.84	76.20	153.3	227.4	304.8	958	1421	1905	3,832	5,685	7,621
9.34	13.94	18.48	37.37	55.75	73.93	149.5	223.0	295.8	934	1394	1848	3,738	5,576	7,394
9.11	13.56	17.93	36.44	54.22	71.71	145.8	216.9	286.9	911	1356	1793	3,645	5,423	7,172
8.88	13.17	17.56	35.50	52.68	70.25	142.0	210.8	281.0	888	1318	1757	3,551	5,270	7,026
8.65	12.90	17.02	34.58	51.59	68.05	138.3	206.4	272.3	865	1290	1702	3,459	5,160	6,807
7.21	11.18	15.34	28.84	44.70	61.36	115.4	178.8	245.5	721	1118	1534	2,885	4,471	6,137
6.17	9.56	13.66	24.67	38.25	54.64	98.7	153.0	218.6	617	956	1366	2,468	3,825	5,465
6.00	9.28	13.22	24.01	37.13	52.90	96.0	148.5	211.6	600	928	1323	2,401	3,713	5,291
5.81	9.01	12.80	23.25	36.02	51.19	93.0	144.1	204.8	581	901	1280	2,325	3,603	5,120
5.05	8.18	11.67	20.19	32.72	46.67	80.8	130.9	186.7	505	818	1167	2,019	3,273	4,668
4.90	7.92	11.27	19.59	31.70	45.08	78.4	126.8	180.4	490	792	1127	1,960	3,169	4,509
4.28	6.75	10.07	17.14	26.99	40.28	68.6	108.0	161.1	429	675	1007	1,714	2,699	4,029
3.51	5.51	8.52	14.84	22.06	34.09	56.2	88.2	136.4	351	551	852	1,404	2,206	3,409
3.15	5.25	7.87	12.59	20.98	31.47	50.4	83.9	125.9	315	525	787	1,259	2,098	3,148
2.84	4.77	7.06	11.36	19.09	28.25	45.5	76.4	113.0	284	477	706	1,137	1,909	2,826
2.57	4.23	6.37	10.28	16.92	25.48	41.1	67.7	101.9	257	423	637	1,028	1,693	2,548
2.30	3.90	5.91	9.19	15.61	23.65	36.8	62.4	94.6	230	390	591	919	1,561	2,365
2.13	3.61	5.46	8.51	14.43	21.83	34.0	57.7	87.3	213	361	546	851	1,444	2,183
1.85	3.22	4.97	7.39	12.88	19.89	29.6	51.5	79.6	185	322	497	739	1,288	1,989
1.62	2.86	4.44	6.49	11.44	17.75	26.0	45.8	71.0	162	286	444	649	1,144	1,775
1.29	2.47	3.97	5.15	9.89	15.88	20.6	39.6	63.5	129	247	397	515	990	1,589
1.09	2.02	3.21	4.35	8.08	12.82	17.4	32.3	51.3	109	202	321	435	808	1,282
.89	1.73	2.84	3.57	6.92	11.35	14.2	27.7	45.4	88.7	173	284	355	692	1,135
.75	1.51	2.45	3.01	6.04	9.81	12.1	24.2	39.3	75.4	151	245	301	604	982
.59	1.17	2.01	2.37	4.70	8.06	9.5	18.8	32.2	59.3	117	201	237	470	806
.48	.98	1.75	1.92	3.92	6.98	7.7	15.7	27.9	48.0	98.0	175	192	392	698
.36	.82	1.41	1.42	3.27	5.64	5.7	13.1	22.6	35.6	81.8	141	142	327	564
.26	.59	1.10	1.02	2.35	4.39	4.1	9.4	17.6	25.6	58.7	110	102	235	440
.18	.47	.90	.73	1.86	3.58	2.9	7.5	14.3	18.2	46.6	89.6	73.0	186	359
.14	.35	.73	.55	1.42	2.93	2.2	5.7	11.7	13.7	35.4	73.1	54.8	142	293
.09	.29	.60	.37	1.17	2.40	1.5	4.7	9.6	9.2	29.2	59.9	36.6	117	240
.06	.19	.42	.25	.75	1.69	1.0	3.0	6.8	6.2	18.8	42.3	24.9	75.2	169
.04	.11	.28	.15	.45	1.13	0.6	1.8	4.5	3.7	11.3	28.2	14.9	45.3	113
.024	.08	.21	.10	.33	.84	0.4	1.3	3.4	2.5	8.4	21.1	9.9	33.4	84.3
.014	.06	.14	.06	.23	.58	0.2	0.9	2.3	1.4	5.8	14.4	5.8	23.3	57.8
.008	.03	.08	.03	.12	.32	0.13	0.5	1.3	0.8	3.0	8.0	3.3	11.9	31.9
.005	.02	.06	.02	.08	..23	0.08	0.3	0.9	0.5	2.1	5.7	2.1	8.3	22.8
.002	.008	.025	.007	.03	.10	0.03	0.12	0.4	0.17	0.8	2.5	0.6	3.1	9.9