The Design of Crude Oil Treating Systems

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Treating systems have long been one of the most expensive and troublesome of all lease surface equipment. Also, there have been available few data for accurately sizing treating equipment, and as a result, treaters are frequently over or under sized.

By selecting the best type of treating system for each locations and accurately determining the exact size of equipment required, considerable money can sometimes be saved. On the following pages are a description of various types of treating systems and their advantages and disadvantages, along with graphs and data for sizing various types of treating equipment.

SELECTION OF THE TYPE OF SYSTEM TO BE USED

In selecting a treating system, a number of factors should be considered to determine the most desirable method of treatment of the crude. These factors to be considered include:

1. Tightness of the emulsion
2. Gravity of the crude oil
3. Corrosiveness of the crude oil and produced water
4. Scaling tendencies of the produced water
5. Quantity of fluid to be treated, and per cent water in the fluid
6. Availability of a sales line for the casing head gas produced

In selection of a treating system perhaps one should first consider the corrosiveness of the emulsion. Pressure type treaters should be used wherever possible, but, because of corrosion of the firebox and the possibility of fire if the firebox fails, they are normally limited to sweet, or mildly corrosive emulsions. For moderately corrosive emulsions, either an atmospheric type treater (heater settling tank) or a gunbarrel (wash tank) should be used. For very corrosive crudes and emulsions, only a gunbarrel with an indirect heat source (indirect heater with cast iron coils, or steam generator with cast iron coils) should even be considered.

For gravity conservation, only pressure type treaters should be used. If pressure type treaters are impractical (because of corrosiveness, etc.), then a large gunbarrel treating tank designed for a minimum treating temperature may be used.

When large quantities of emulsion are to be treated (2,000 to 3,000 barrels per day or more), gunbarrel treating tanks with external heat sources are normally used, because of the high costs of large pressure type treaters. Heat may be supplied by either a direct heater (for sweet, or slightly corrosive crudes) or by an indirect, water bath type heater (for corrosive emulsions). While the direct heaters may be used reasonably for treating tank temperatures up to 120°, the indirect heater heat source is usually limited to 90 to 100 maximum treating tank temperature. If an indirect heat source is required for treating temperatures greater than 100 , then a steam generator (15 psi steam heating boiler) should be used connected to cast iron coils installed in the gunbarrel.

The following is a resume of various types of treating systems and recommended applications for each:

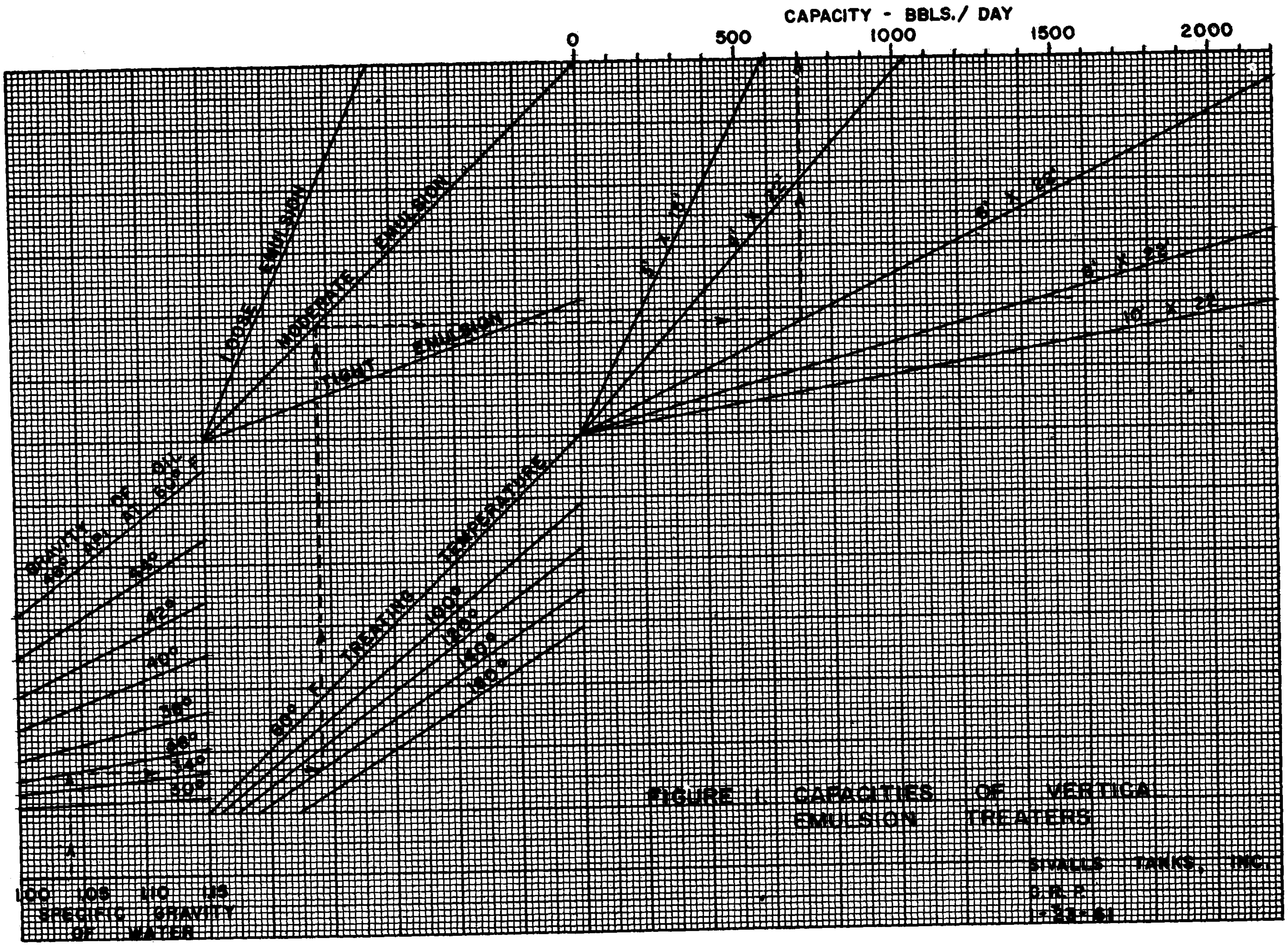
Treating System	Recommended Applications
1. Pressure Type Treater	Medium to high gravity oils (35 API, plus), when sweet or slightly corrosive, with a sales line available for casing head gas. Normally used in preference to all other types of treating systems wherever possible for conservation of oil gravity and recovery of rich vapors.
2. Atmospheric Type Treaters	Sweet to moderately corrosive oils of low gravity (less than 35° API).
3. Gunbarrel Tanks without heat	Loose emulsions of all gravity oils, with inlet temperatures of 60° to 80° or more.
4. Gunbarrel Tanks with direct heaters	Sweet or slightly corrosive oils of all gravities; for both loose and tight emulsions.
5. Gunbarrel Tanks with indirect heaters	Moderately or very corrosive emulsions of all gravity oils; normally used for only loose or moderate emulsions. Also recommended where scaling may be expected on heated surfaces.
6. Gunbarrel Tanks with steam generators and coils	Moderately or very corrosive emulsions of all gravities; normally used only for moderate to tight emulsions, where higher treating temperatures are required than those obtainable with an indirect heater.

SIZING TREATING EQUIPMENT AND SYSTEMS

General Theory

In the separation of any oil and water mexture, one may normally expect the heavier water droplets to settle out of the oil phase and oil particles to rise out of the water phase because of the difference in the densities of the two phases. However there this separation may be prevented from occurring by two phenomena: (1) if the droplets are too small in diameter, they may be suspended indefinitely by Brownian movement; (2) the droplets may carry like electrical charges because of dissolved ions, and these charges cause the droplets to repulse each other, while they fail to coalesce into large enough droplets to settle (or rise) rapidly. In crude oil-water emulsions, one seldom finds droplets occurring naturally small enough to be suspended by Brownian movement. However, the droplets of water in water-in-crude oil emulsions do frequently carry electrical charges, but proper chemical treatment usually will neutralize these charges.

Assuming proper chemical treatment, the separation of an oil and water emulsion becomes essentially a mechanical problem; and settling rates for various diameter droplets may be calculated for any gravity and viscosity of the two fluids by Stokes law. (According



CAPACITY - BBLS./ DAY
0
500
1000
1500
2000
LOOSE EMULSION
MODERATE EMULSION
TIGHT EMULSION
TREATING TEMPERATURE
60° F
100°
120°
140°
160°
GRAVITY °API AT 60° F OF OIL
44°
42°
40°
38°
30°
100 105 110 115
SPECIFIC GRAVITY OF WATER
FIGURE 1. CAPACITIES OF VERTICAL EMULSION TREATERS
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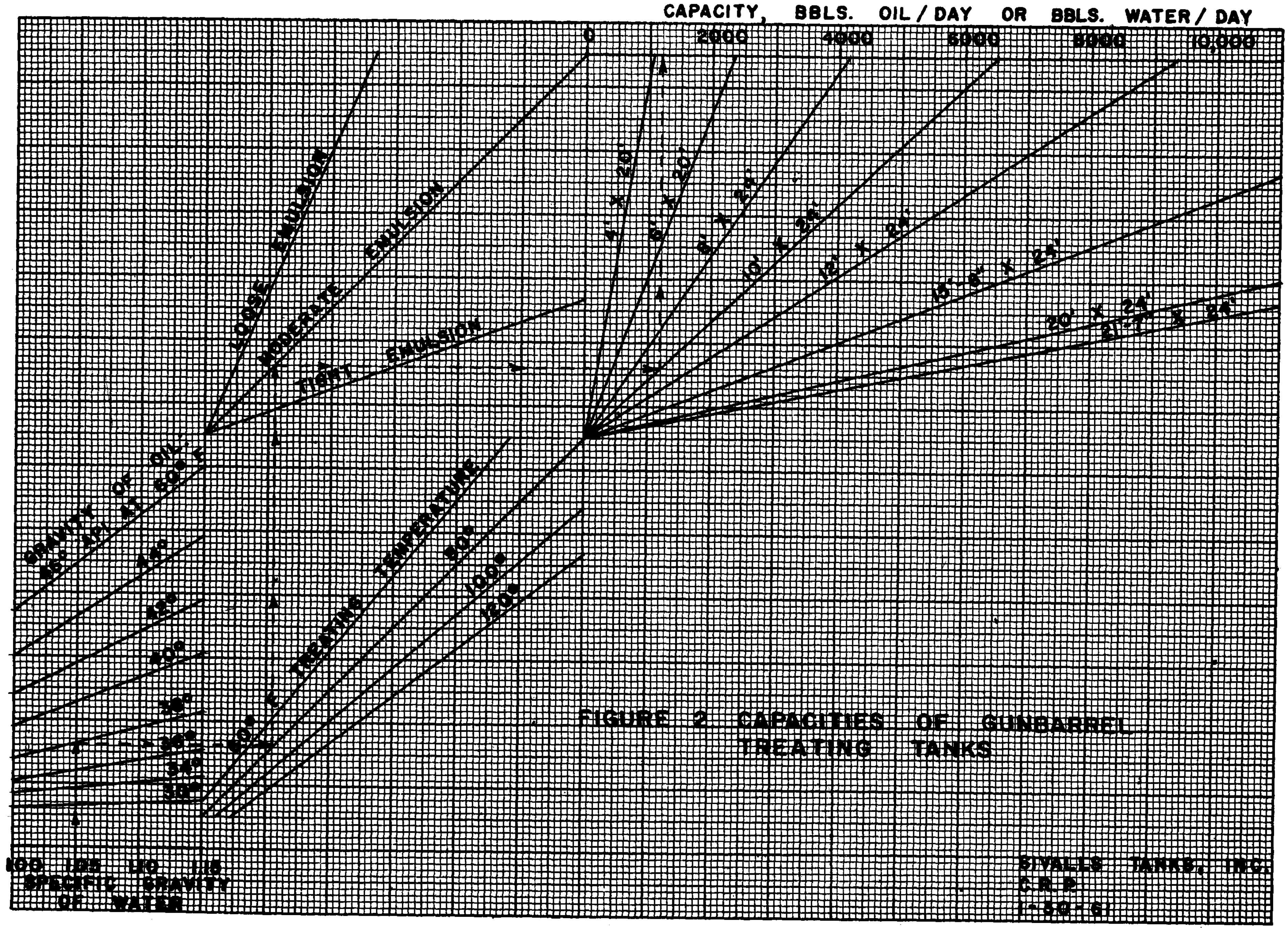

FIGURE 2 CAPACITIES OF GUNBARREL TREATING TANKS

to Stokes law, the settling velocity of spheres through a fluid is directly proportional to the difference in densities of the sphere and the fluid, and inversely proportional to the viscosity of the fluid and the square of the diameter of the sphere.) From the settling rate of the spherical droplets, and the cross sectional area of the settling zone, one may calculate the capacity of any treating vessel for the conditions for which the settling rate was calculated.

In the formulas which follow, there appears a universal constant C, which varies according to the diameter of the water particles in the emulsion. For the purposes of these calculations, the following represents the assumed average diameter of water particles in various types of emulsions with the respective value of the constant C.

Emulsion Characteristic	Water Droplet Diameter in Microns (meters x 10^{-6})	C
Free Water	200	1,101
"Loose" Emulsion	150	619
"Moderate" Emulsion	100	275
"Tight" Emulsion	60	99.1

Capacities of Treaters and Gunbarrel Tanks

In determining the capacity of a gunbarrel treating tank or a treater, one should first assume a treating temperature. The following represents average treating temperatures normally used for various conditions and may be used for an initial assumed temperature:

Emulsion	Normal Treating Temperatures	
Characteristic	Treaters	Gunbarrels
"Loose" Emulsion	100 -120	80 -100
"Moderate" Emulsion	120 -140	100 -120
"Tight" Emulsion	140 -180	120 Plus

After assuming the treating temperature, one determines the specific gravities of the water and oil and the viscosity of the oil at the assumed treating temperature and calculates the capacity of any vertical treater or gunbarrel tank. The following formula is used:

$$W = C\frac{(Sw - So)}{V}(0.785\, D^2)$$

where

W = Capacity, BOPD
C = Constant from above table
Sw = Specific gravity of the water at the treating temperature
So = Specific gravity of the oil at the treating temperature
V = Viscosity of the oil in centipoise at the treating temperature
D = Diameter of the treating vessel in feet

For horizontal treaters, the following formula is used:

$$W = C\frac{(Sw - So)}{V}(lh)$$

where

W, C, Sw, So, and V are as listed above
l = Length of the interface area in the settling section of the treater in feet
h = Width of the interface area in the settling section of the treater in feet

For Mid-Continent crude oils of average viscosities, these formulas have been incorporated into composite graphs in Figs. 1 and 2 for treaters and gunbarrels respectively to facilitate calculating capacities for standard size vessels at various conditions.

It should be noted that the above formulas are for settling velocities (and therefore capacities) for water particles in oil, or water-in-oil emulsions. For inverted emulsions (oil-in-water emulsions), the viscosity of the water at the treating temperature rather than the viscosity of the oil should be used in the formula. However in actual practice, most emulsions are a combination of oil-in-water, and water-in-oil; but, for almost all emulsions, the settling rate of the water-in-oil emulsions is much slower than is that of the oil-in-water settling rate; therefore, only the water-in-oil emulsion need be considered in sizing a treating system.

Heat Source Design for Treating Systems

After the treating vessel has been sized, the next step is to determine the amount of heat required to raise the inlet emulsion stream to the assumed or desired treating temperature. This amount of heat mav be calculated with the following formula:

$$Q = W'(6.25 + 0.0833\,X)(Tt - Ti)$$

where

Q = Heat required, BTU/hr
W' = Bbls. emulsion/day treated
X = per cent of water in the emulsion
Tt = Treating temperature
Ti = Inlet temperature

Fig. 3 is a graphical solution of the above formula. Once the heat required is determined, the heat source may be designed. The following is a resume of the various types of heating sources used and their design criteria:

1. Direct fired heater: This type heating element is normally designed by heat flux. The following heat fluxes may be used for safe design purposes:

Fluid Around Firebox	Heat Flux, BTU/hr-sq ft of firebox area
Oil	6,000-8,000
Salt Water	10,000
Fresh Water	12,000
Boiling Water	15,000

2. Indirect (water bath) heater: This type heating source should be designed by standard heat exchange methods, by the following formula:

$$Q = U\,A\,Td$$

where:

Q = Heat transferred, BTU/hr
U = Heat Transfer coefficient, BTU/hr - F - sq ft
A = Coil area
Td = Average temperature difference

$$= \frac{(Tb - Ti) + (Tb - To)}{2}$$

where:

Tb = Water bath temperature

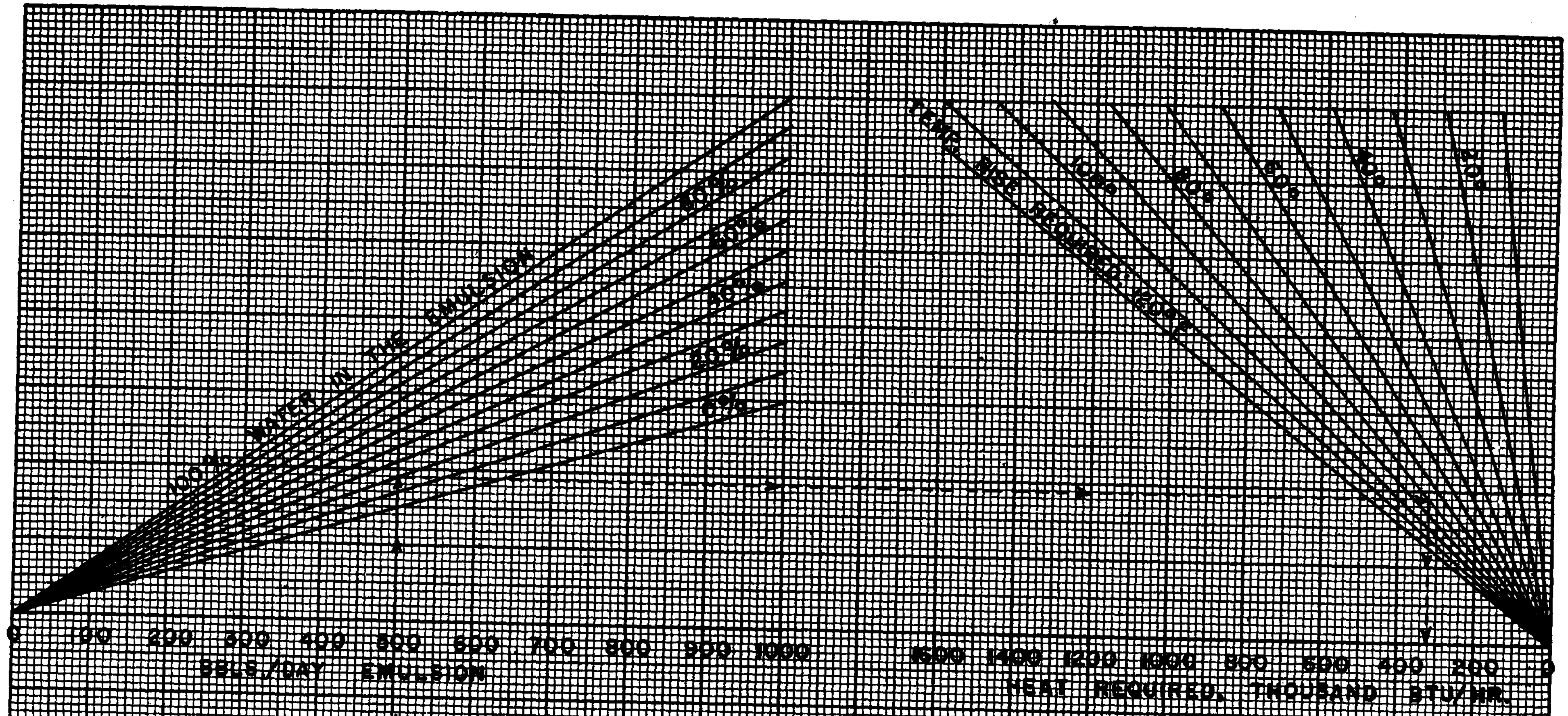

FIGURE 3. HEAT REQUIRED FOR
HEATING OIL-WATER EMULSIONS

(NOTE: FOR 0-10,000 BBL./DAY RANGE,
MULTIPLY "BBLS./DAY EMULSION" AND
"HEAT REQUIRED" BY 10.)

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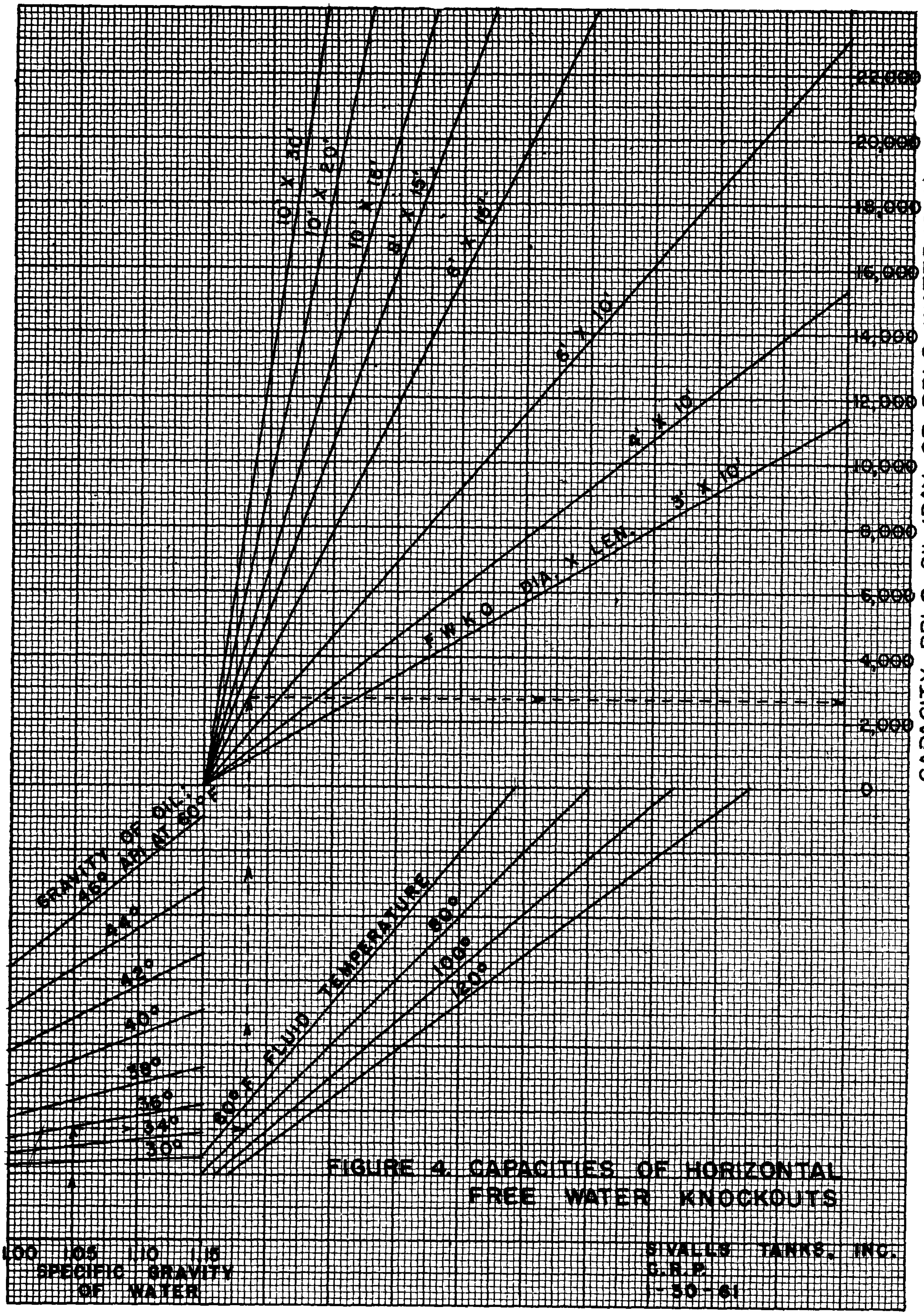

FIGURE 4. CAPACITIES OF HORIZONTAL FREE WATER KNOCKOUTS

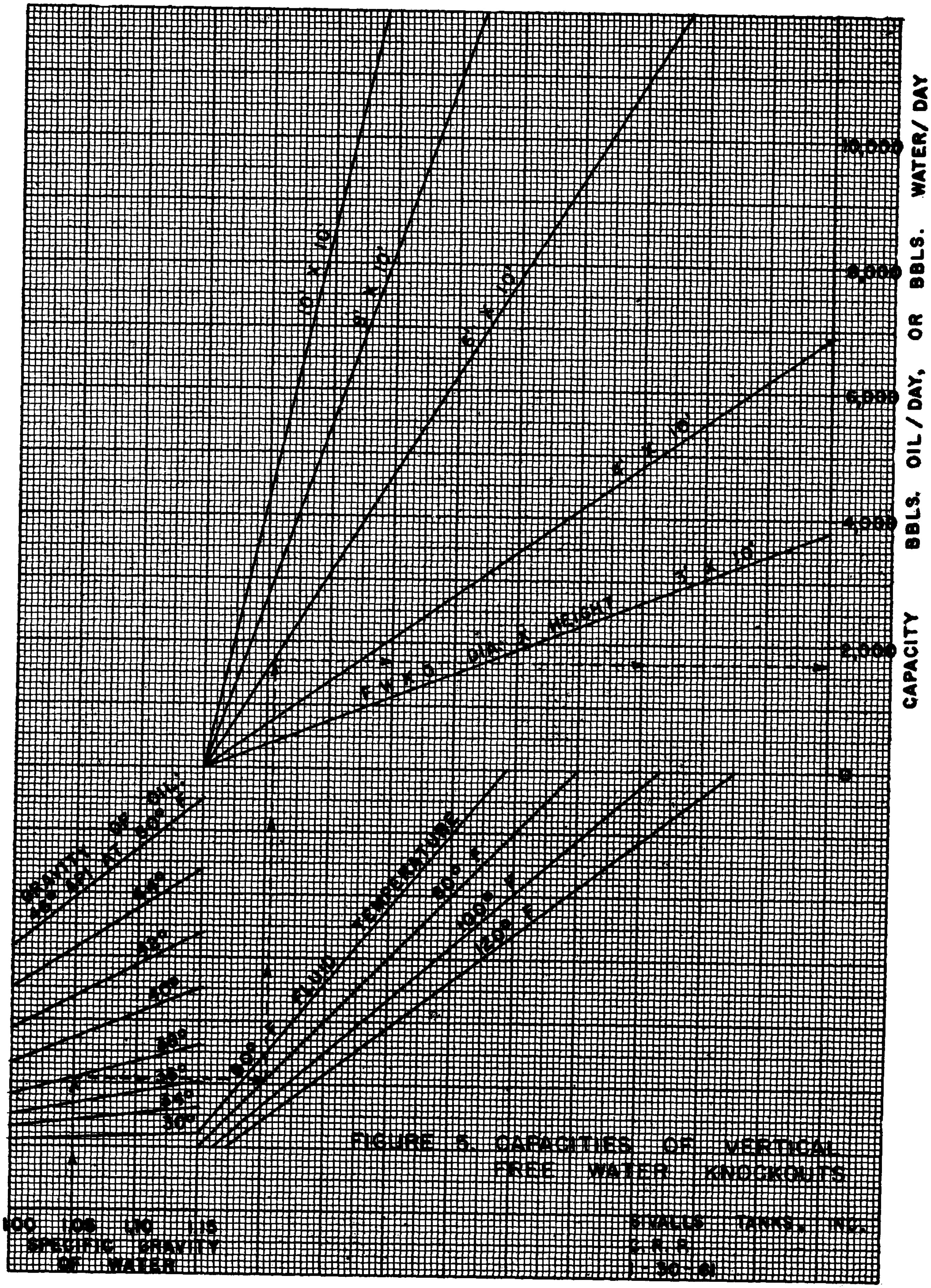

FIGURE 5. CAPACITIES OF VERTICAL FREE WATER KNOCKOUTS

Ti = Emulsion inlet temperature
To = Emulsion outlet temperature

For the above, the following represents average values of U:

Flow Rate Bbls./day	2" Pipe		3" Pipe		4" Pipe	
	100% oil	100% water	100% oil	100% water	100% oil	100% water
500	9.5	107	4.5	69	3.3	49
1,000	27.8	126	10.5	96	5.0	75
1,500	42.3	136	20.5	110	12.2	91
2,000	53.0	142	28.5	118	17.0	100
2,500	62.8	150	34.5	125	21.8	107
3,000	----	---	39.0	129	25.7	112
4,000	----	---	46.2	137	32.0	120

For compositions of emulsions between 100 per cent oil and 100 per cent water, an interpolation between the above values is made.

3. Steam generator with coil in treating vessel: This type heating element may also be designed by standard heat exchange methods, using the formula listed in (2) above, with the following value for U and Td:

$$U = 67.5 \text{ BTU/hr - sq ft - }^{\circ}\text{F}$$

$$Td = Ts - Tt$$

where

Ts = Temperature of the steam (220° to 250°, depending on steam pressure)
Tt = Treating temperature

In determining the total heat input required for a treating system being designed, the maximum amount of heat loss anticipated from the shell of the treating vessel should be added to the heat required to raise the emulsion to the desired treating temperature. Heat loss from an uninsulated vessel may be estimated with the following formula:

$$Q = K(DH)(Tt - Ta)$$

where

Q = Heat loss in BTU/hr
K = A Constant:
For 20 mhp wind: 15.7
For 10 mhp wind: 13.2
For 5 mhp wind: 9.8
Still air: 6.3
D = Diameter of treating vessel, in ft
H = Shell height of treating vessel, in ft
Tt = Treating temperature
Ta = Design outside ambient temperature

For insulated treating vessels, heat losses are usually negligible.

Free Water Knockout Design

Although free water knockouts and three-phase separators are not actually treating devices, they are used to separate water and oil, and design procedure for them is similar to that for treating systems. Therefore, sizing formulas and curves are included with this paper.

Vertical free water knockouts may be sized with the following formula:

$$W = \frac{C(Sw - So)}{V}(0.785\, D^2)$$

where

W = Capacity in BPOD
C = Constant from table (C = 1101 for true free water)
Sw = Specific gravity of the water at the temperature of the fluid
So = Specific gravity of the oil at the temperature of the fluid
V = Viscosity of the oil at the fluid temperature, in centipoise
D = Diameter of the vessel in ft

Horizontal free water knockouts may be sized with the following formula:

$$W = \frac{C(Sw - So)}{V}(lh)$$

where

W, C, Sw, So, and V are as listed above
l Length of the interface area in the settling section in ft
h Width of the interface area in the settling section in ft

Figs. 4 and 5 are graphical solutions of the above equations for Mid-Continent crude oils of average viscosities.

SUMMARY

The treating system represents one of the most expensive and troublesome parts of any lease surface installation. Operators can not only save money, but also eliminate many operating problems, increase gravity of the stock tank liquids, and reduce shrinkage by carefully selecting and completely designing the treating system.

After selection of the treating system to be used, one may readily use Stokes law to size the treating vessel. Sizing calculations have been consolidated for graphical solution in Figs. 1, 2, 4 and 5. Fig. 3 is a graphical solution of the heat input required.