GEORGIA IRON WORKS CO.
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GIW

HYDRAULIC SLIDE RULE

- INSTRUCTIONS
- FORMULAS (as applied to a liquid-solids mixture)
- CHARTS

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HYDRAULIC SLIDE RULE

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- CHARTS

by

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PREFACE

The following manual will give a brief explanation in the use of all scales apearing on the GIW Hydraulic Slide Rule. It is assumed the reader has a basic knowledge in the theory and operation of a slide rule, therefore this phase is omitted. In each type of problem, the pertinent formula will be given, the scales involved pointed out and elaborted on, and two example problems worked.

Also included in this manual is the section entitled, "Formulas Used in Pumping Liquids with Solids in Suspension." The use of these formulas with enclosed charts, and aided by the GIW Hydraulic Slide Rule should simplify and greatly reduce the time necessary in solving most practical dredge and mining pump problems.

In the use of the slide rule and in all of the following definitions and calculations, the slurry (liquid-solids mixture) is treated as a pseudo-fluid. This approach is not-supported by mathematical calculations, however the results obtained are approximately correct and within the range of accuracy of the other variables involved. For example, to determine the specific gravity of a slurry or pseudo-fluid, one might proceed as follows:

a. Weigh a container of slurry, being careful to mark the slurry level in the can.

b. Empty the slurry from the can and obtain the weight of the can.

c. Refill the can with fresh water to the mark made in step (a) and determine the weight.

d. Subtract the can weight (b) from the weights obtained in (a) and (c).

The specific gravity of the pseudo-fluid is simply the ratio of the weights obtained in (d) above.

After becoming familiar with the slide rule and formulas, it will become apparent that the following very necessary items are not readily known: "C" and "H_{se}".

The above "C" is a contant appearing in the empirical equation by Hazen & Williams. As formulated, the equation was intended for use with clear water and the constant "C" was intended to account for pipe roughness. However, the same equation may be used for a liquid-solids mixture if the value of "C" is permitted to account for the effects of the foreign particles. When pumping slurries, the pipe wall is naturally polished; thus, the variation of "C" in pumping slurries is the effect of the solids upon the flow pattern. Since the mechanics of solids transport is not highly developed, the only practical plan is to perform experiments with the solids to be transported and to make an experimental determination of the appropriate "C" value. In obtaining the value of "C", h_f in the formula should be in units of ft-lb/lb of pseudo-fluid/100 ft. pipe. By using the pseudo-fluid, the effect of solids concentration is reduced, thereby making the resulting "C" value more relevant to the nature of the solids.

"H_{se}" as appears above is the pump head (ft-lb/lb of pseudo-fluid) lost due to the effect of the solids. It is the difference between the head that would be produced by a pump on a true fluid and the head that is actually produced when pumping a pseudo-fluid of the same specific gravity. As a point of interest, in most cases, the solids passing through a pump increase the pressure of the liquid instead of detracting from it. This is possible since the solids leave the impeller at a higher momentum per unit volume than the liquid. In decelerating, part of the kinetic energy lost by the solids is converted into liquid pressure. This results in keeping the value of "H_{se}" small.

The above "C" and "H_{se}" vary depending on the slurry concentration, liquid viscosity, and particle size, shape, and specific weight. Approximate values of "C" and "H_{se}" can be supplied a customer by Georgia Iron Works Company if a thorough description or sample of the solids is available and the desired slurry concentration is known. This information is made possible by tests in the GIW hydraulic laboratory, field tests, and the knowledge gained through more than 40 years experience in the field of pumping liquids with solids in suspension. When desired, laboratory tests or field tests may be performed on a particular slurry for a more accurate determination.

There are additional points which should be clarified. Kinetic energy "$v^2/2g$" is taken as calculated in units of ft-lb/lb of pseudo-fluid. This is accurate if the pipeline velocity of the solids is taken as the same as that of the liquid. Static head or the difference in liquid elevation which the pump must overcome is taken in units of ft-lb/lb of pseudo-fluid as measured. This is accurate only if all the material is in suspension as is the case of a vertical pipe. Finally, the value "k_{pf}" (resistance coefficient for valve or pipe fitting) is taken from the Hydraulic Institute Pipe Friction Manual. The head loss as calculated by the above method is taken in units of ft-lb/lb of pseudo-fluid. Any error introduced by using the above procedures should be relatively small and will be disregarded until such time as a more accurate approach is developed.

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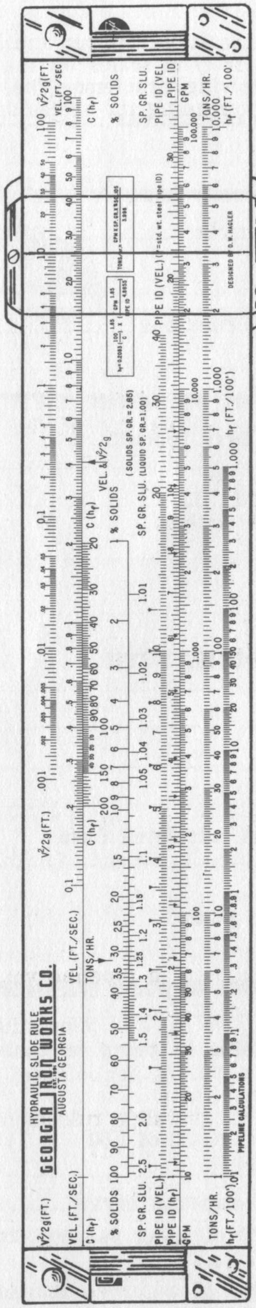
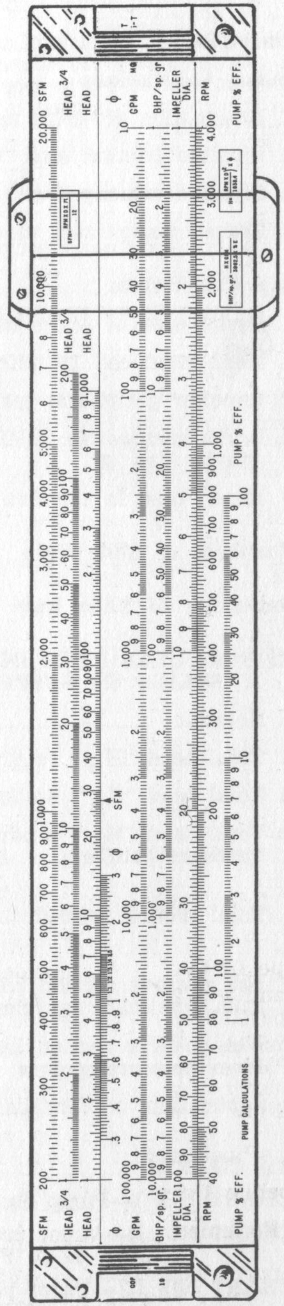


Pipeline Calculations



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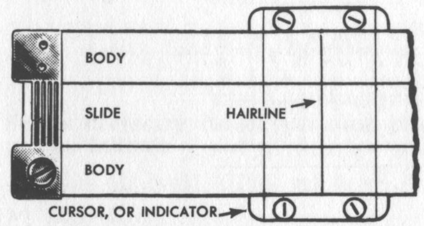
PART I

GIW HYDRAULIC SLIDE RULE

INTRODUCTION

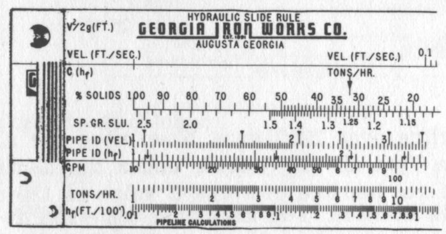
The slide rule consists of three parts: (1) the stator (upper and lower bars); (2) the slide; (3) the cursor or indicator. The scales on the bars and slide are arranged to work together in solving problems. The hairline on the indicator is used to help the eyes in reading the scales and in adjusting the slide.



Each scale is named in abbreviated form on either end of the rule.

PIPELINE CALCULATIONS

1. Designation of Scales Used for Pipeline Calculations



$v^2/2g$=Velocity head (kinetic energy); ft-lb/lb
Vel.=Pipeline liquid or slurry velocity; ft/sec
C (h_f)=Hazen-Williams constant "C" being used to account for the effect of solids upon the flow pattern
% Solids=ratio of the solids weight to the total weight of slurry expressed in per cent; %
Sp. Gr. Slu.=Specific gravity of slurry or pseudo-fluid; deminsionless
Pipe ID (Vel.)=Pipe inside diameter (scale used in pipeline velocity and $v^2/2g$ calculations); inches
Pipe ID (h_f)=Pipe inside diameter (scale used in h_f calculations); inches
GPM=volume rate of flow of the mixture in gallons per minute; gpm
Tons/hr=Transportation rate of dry solids; tons/hr
Note: Transportation rate as obtained from the slide rule is based on a solids sp. gr. of 2.65 and liquid sp. gr. of 1.00.
h_f =Pipeline friction loss; ft.lb/lb/100 ft. pipe

2. Pipeline Friction Loss "h_f"

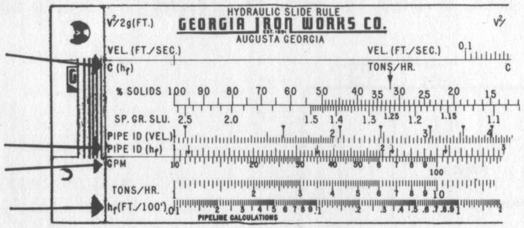
Formula:

$$h_f = 0.2083\left(\frac{100}{C}\right)^{1.85} \times \frac{GPM^{1.85}}{\text{Pipe ID}^{4.8655}}$$

The above is an empirical formula by Hazen and Williams. See the Preface for an explanation of the use of "C" as applied to a liquid-solids mixture.

Scales necessary for determining h_f are as follows:

Pipe ID (h_f), GPM, C and h_f



Example problems:

A. Given:

- Flow=2800 gpm
- Pipe ID=8" standard weight steel pipe (use arrow on slide rule)
- C=120
- Percent solids by weight=20%
- Solids sp. gr.=2.65
- Liquid sp. gr.=1.00

Find:

- h_f
- Pressure loss (psi) per 100 ft. pipe

To obtain h_f set the hairline over 2800 gpm. Now move the slide so as to put 8" (arrow) on the Pipe ID (h_f) scale under the hairline. Without moving the slide, move the hairline over the C value of 120 and read the resulting h_f under the hairline. The answer is h_f =14.4 ft-lb/lb/100 ft.

In order to convert h_f to pressure loss (psi) per 100 ft. pipe, determine the specific gravity of the slurry. This is done by moving the hairline over 20% on the % solids scale and reading a slurry specific gravity of 1.142 under the hairline on the sp. gr. slu. scale below.

$$\frac{14.4\ \text{ft-lb.}}{\text{lb. pseudo-fluid}} \times \frac{1.142\ \text{lb. pseudo-fluid}}{\text{lb. water}} \times \frac{\text{psi}}{2.31\ \text{ft-lb/lb water}} = 7.12\ \text{psi}$$

The pressure loss (psi) per 100 ft. pipe is 7.12 psi.

B. Given

- Flow=11,000 gpm
- Pipe ID=16" ID
- C=135
- Percent solids by weights=40%
- Solids sp. gr.=2.65
- Liquid sp. gr.=1.00

Find:

- h_f
- Pressure loss (psi) per 100 ft. pipe

Answer:

- h_f =4.96 ft-lb/lb/100 ft
- Pressure loss=2.86 psi/100 ft.

3. Pipeline velocity "vel" (ft/sec) or velocity head "v^2 /2g" (ft.)

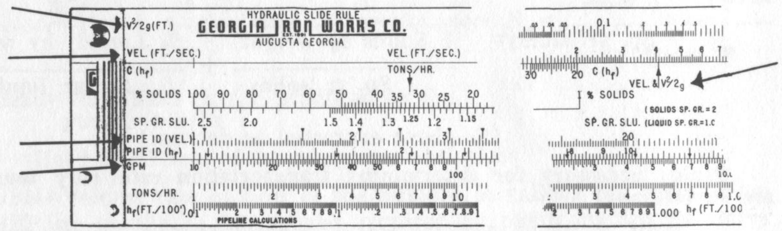
Formula:

a. Pipeline velocity "vel." (ft/sec)= $\frac{0.4085\text{xGPM}}{\text{Pipe ID}^2}$

b. Velocity head "v^2 /2g" (ft.)= $\frac{v^2}{2g}$

Scales necessary for determining pipeline velocity and velocity head are as follows:

Pipeline ID (vel), GPM, vel & v^2 /2g arrow, vel (ft/sec), & v^2 /2g (ft.)



Example Problems:

A. Given:

- Flow=2800 gpm
- Pipe ID=8" standard weight steel pipe (use arrow)
- Percent solids by weight=20%
- Solids sp. gr.=2.65
- Liquid sp. gr.=1.00

Find:

- Pipeline velocity (ft/sec)
- Velocity head ft-lb/lb of pseudo-fluid

To obtain the pipeline velocity and velocity head set the hairline over the flow of 2800 gpm. Now move the slide so as to put 8" (arrow) on the Pipe ID (vel.) scale under the hairline. Without moving the slide, move the hairline over the vel. and v^2 /2g arrow and read the resulting pipeline velocity and velocity head under the hairline. The pipeline velocity is 17.96 ft/sec and the velocity head is a 5.01 ft-lb/lb of pseudo-fluid. The slurry % solids, solids specific gravity, and liquid specific gravity have no effect on the answer.

B. Given:

- Flow=11,000 gpm
- Pipe ID=16" ID
- Percent solids by weight=40%
- Solids sp. gr.=2.65
- Liquid sp. gr.=1.00

Find:

- Pipeline velocity
- Velocity head "v^2 /2g"

Answer:

- Pipeline velocity=17.55 ft-sec
- Velocity head=4.79 ft.lb/lb

4. Transportation rate of dry solids in tons/hr.

Formula:

$$\text{Transportation rate (dry solids tons/hr)} = \frac{\text{GPM} \times \%\ \text{Solids} \times \text{sp. gr.}}{3.998}$$

Note: The above sp. gr. refers to the slurry sp. gr.

Note: The transportation rate as obtained from the slide rule is based on a solids sp. gr.=2.65 and a liquid sp. gr.=1.00. However, the above formula is good for any sp. gr. solids or liquid.

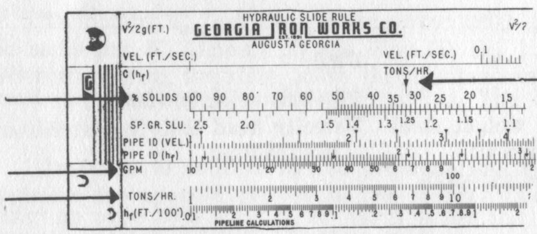
Note: To use the above formula for any sp. gr. solids or liquid, the following formula is helpful in determining the slurry sp. gr. when the slurry density (% solids by weight) is known:

$$\text{Sp. gr. slurry} = \frac{1}{\frac{\%\ \text{Solids by weight}}{\text{Sp. gr. solids}} + \frac{\%\ \text{Liquid by weight}}{\text{Sp. gr. liquid}}}$$

(% above expressed as decimal)

Scales necessary for determining transportation rate (dry tons/hr) are as follows:

GPM, % Solids, Tons/hr arrow, and Tons/hr



Example problems:

A. Given:

Flow=2800 gpm
Percent solids by weight=20%

Find:

Transportation rate of dry solids

To obtain transportation rate of dry solids in tons/hr, set the hairline over 2800 gpm. Now move the slide so as to put 20% on the % solids scale under the hairline. Without moving the slide move the hairline over the tons/hr arrow and read the resulting transportation rate. The answer is 160 tons/hr.

B. Given:

Flow=11,000 gpm
Percent solids by weight=40%

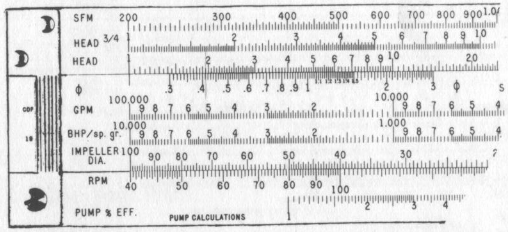
Find:

Transportation rate of dry solids

Answer:
Transportation rate of dry solids= 1466 tons/hr.

PUMP CALCULATIONS

1. Designation of Scales for Pump Calculations



SFM=Impeller peripheral speed in surface feet per minute; sfm

Head$^{3/4}$ (Used in calculation of specific speed: $N_S = \frac{\text{RPM} \times \sqrt{\text{GPM}}}{\text{Head}^{3/4}}$)

Head=Total head change produced by the pump; ft-lb/lb

ϕ =Head coefficient of the pump; dimensionless

GPM=Volume rate of flow of the mixture in gallons per minute;gpm

BHP/sp. gr.=Brake horsepower required by pump divided by slurry specific gravity; hp

Note: To obtain BHP, multiply the above by the slurry (pseudo-fluid) sp. gr.

Impeller dia.=Pump impeller diameter; inches

RPM=Angular velocity of the pump impeller and shaft; rpm

Pump % Eff.=Efficiency of the pump in percent; %

2. Head produced by pump

Formula:

$$H = \left(\frac{\text{RPM} \times \text{Impeller Dia.}}{1838.4}\right)^2 \times \phi \quad \text{(For a true fluid)}$$

The above formula is developed from the theory that head produced by a pump can be expressed as a function of $u^2/2g$. "u" is the impeller peripheral speed in surface feet per second. As applied to a particular pump, $u^2/2g$ is multiplied time ϕ so as to account for impeller vane and pump casing design.

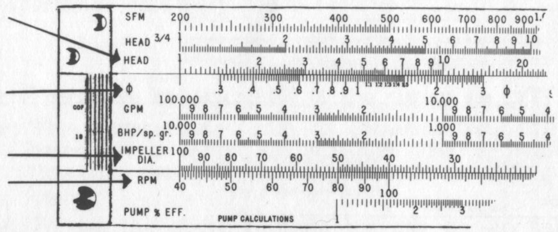
Note: The above formula and the slide rule obtain head of a true fluid. When applied to a slurry, this head does not take into account the additional head loss due to solids. This is because a pump will not produce as much head when pumping a slurry or pseudo-fluid as it would on a true fluid of the same sp. gr. On a slurry, the above formula becomes:

$$H = \left(\frac{\text{RPM} \times \text{Impeller Dia.}}{1838.4}\right)^2 \times \phi - H_{se} \text{ ; ft-lb/lb of pseudo-fluid}$$

H_{se} =Head loss due to solids; ft-lb/lb of pseudo-fluid

Scales necessary for determining head are as follows:

RPM, Impeller Dia., ϕ, & Head



Example problems:

A. Given: | Find:

Impeller Dia.=24.75" — Head produced by pump
RPM=900 rpm
ϕ =1.28 (4 vanes)
Percent solids by weight=20%
Solids sp. gr.=2.65
Liquid sp. gr.=1.00
H_{se} =10 ft.-lb/lb (see Preface)

To find head produced by a pump, set the hairline over 900 rpm. Now move the slide so as to put 24.75" on the impeller diameter scale under the hairline. Without moving the slide, move the hairline over ϕ =1.28 and read the resulting head under the hairline. The answer is 188 ft-lb/lb true fluid.

Head=188-10 equals 178 ft.-lb/lb of pseudo-fluid
The head produced by the pump=178 ft-lb/lb.

B. Given: | Find:

Impeller Dia.=39" — Head produced by pump
RPM=585 — Answer:
ϕ=1.28 (4 vanes) — Head=197 ft-lb/lb true fluid
H_{se} =10 ft-lb/lb — Head=197-10 equals 187 ft-lb/lb
Percent solids by weight=40%
Solids sp. gr.=2.65
Liquid sp. gr.=1.00

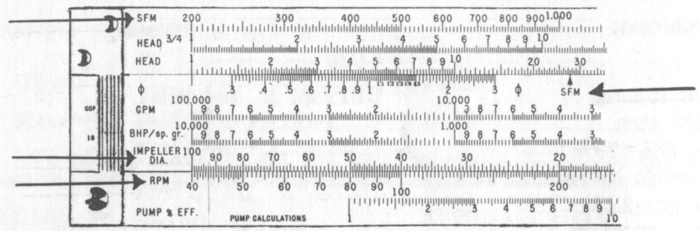
3. Impeller peripheral speed in surface feet per minute "SFM"

Formula:

$$SFM=\frac{RPM \times Impeller\ Dia.\ (Inches) \times \pi}{12}$$

Scales necessary for determining SFM are as follows:

RPM, Impeller Dia. (inches), SFM arrow, SFM



Example problems:

A. Given: | Find:

RPM=900 rpm — SFM
Impeller dia.=24.75"

To obtain SFM set the hairline over 900 rpm. Now move the slide so as to put 24.75" on the impeller diameter scale under the hairline. Without moving the slide, move the hairline over the SFM arrow and read the resulting SFM under the hairline. The answer is 5,830 ft/min.

B. Given: | Find:

Impeller dia.=39" — SFM
RPM=585 rpm — Answer:
SFM=5,970 ft/min.

4. Brake horsepower "BHP" divided by slurry specific gravity "sp. gr."

Formula:

$$BHP=\frac{Head \times GPM \times sp.\ gr.}{3962.5 \times \%\ Eff.}$$

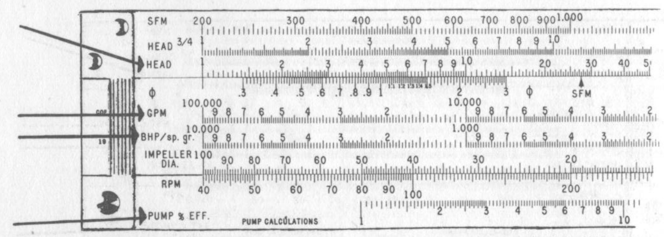
$$BHP/sp.\ gr.=\frac{Head \times GPM}{3962.5 \times \%\ Eff.}$$

Note: If the above formula is applied when pumping a slurry, the head must be in units of feet of slurry (ft-lb/lb of pseudo-fluid). If pump head is calculated on the slide rule or taken from a characteristic head capacity curve, the head loss due to solids (H_{se}) will not be accounted for. A pump will not produce as much head when pumping a slurry as it would on a true fluid of the same sp. gr. See page 11 for method of calculating pump head when pumping a slurry.

Note: To obtain BHP, multiply BHP/sp. gr. (obtained from slide rule) times the slurry sp. gr.

Scales necessary for determining BHP/sp. gr. are as follows:

Head, GPM, % E, and BHP/sp. gr.



Example problems:

A. Given:

Head=178 ft-lb/lb
Flow=2800 gpm
Pump % Eff.=70%
Percent solids by weight=20%
Solids sp. gr.=2.65
Liquid sp. gr.=1.00

Find:

BHP/sp. gr. and BHP

To obtain BHP/sp. gr., set the hairline over 178 feet of head. Now move the slide so as to put 2800 gpm under the hairline. Without moving the slide, move the hairline over 70% on the Pump % Eff. scale and read the resulting BHP/sp. gr. The answer is 179.7 hp.

To obtain BHP required by the pump, multiply the above BHP/ sp. gr. by the slurry sp. gr. (The slurry specific gravity is obtained by setting the hairline over 20% on the % Solids scale and reading the slurry specific gravity under the hairline on the Sp. gr. slu. scale below. The answer is specific gravity of 1.142.)

179.7 hp x 1.142.=205.2 hp
The pump would require 205 hp.

B. Given:

Pump Head=187 ft-lb/lb
Flow=11,000 gpm
Pump % Eff.=68%
Percent solids by weight=40%
Solids sp. gr.=2.65
Liquid sp. gr.=1.00

Find:

BHP/sp. gr.
BHP

Answer:

BHP/sp. gr.=763 hp
BHP=763x1.332 equals 1016 hp

5. Head$^{3/4}$ used in calculating specific speed

Formula:

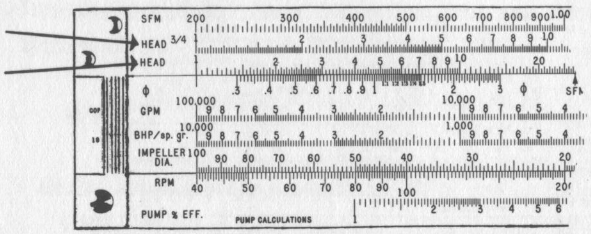
$H^{3/4}$ is used in calculating specific speed.

$$N_S \text{ (Specific speed)} = \frac{RPM \times \sqrt{GPM}}{Head^{3/4}}$$

Note: Specific speed is used in classifying a pump as to type. As such, the pump head should be expressed in ft-lb/lb when pumping a true fluid.

Scales necessary for determining Head$^{3/4}$ are as follows:

Head and Head$^{3/4}$



Example problems:

A. Given:

Head=188 ft-lb/lb true fluid

Find:

Head$^{3/4}$

To obtain Head$^{3/4}$, set the hairline over 188 on the Head scale and read the resulting Head$^{3/4}$ under the hairline. The answer is 50.8.

B. Given:

Head=197 ft-lb/lb true fluid

Find:

Head$^{3/4}$

Answer:

Head$^{3/4}$ =52.6

ADJUSTMENT OF SLIDE RULE

Each rule is accurately adjusted before it leaves the Pickett & Eckel factory. However handling during shipment, dropping the rule, or a series of jars may loosen the adjusting screws and throw the scales out of alignment. Follow these simple directions for slide rule adjustment.

1. **Cursor window hairline adjustment.**

A. Line up the hairline on one side of the rule at a time.

(1) Lay rule on flat surface ("Pipeline Calculations" facing up) and loosen adjusting screws in end plates.

(2) Line up Pipe ID (h_f) index with the GPM index. Then align the index marker on the upper stator with the index marker on the slide.

(3) Tighten screws in end plates.

(4) Loosen cursor window screws. Slip a narrow strip of thin cardboard (or 3 or 4 narrow strips of paper) under center of window.

(5) Align hairline with the GPM index and upper stator index and tighten cursor window screws. Check to see that window surfaces do not touch or rub against rule surfaces.

Note: The narrow strip of cardboard under the window will prevent possible distortion or "bowing in" of the window when screws are tightened. "Bowing in" may cause rubbing of window against rule surface with resultant wear or scratches.

B. Line up hairline on reverse side of rule.

(1) Loosen all 3 cursor window screws.

(2) Place narrow strip of thin cardboard under window to prevent "bowing in" when screws are tightened.

(3) Align hairline and indices on first side of rule, then turn rule over carefully to avoid moving cursor.

(4) Align hairline with indices and tighten cursor screws.

(5) Check to see that window surfaces do not touch surfaces of rule during operation.

2. **Slider tension adjustment**—Loosen adjustment screws on end brackets; regulate tension of slider, tighten the screws using care not to misalign the scales. The adjustment needed may be a fraction of a thousandth of an inch, and several tries may be necessary to get perfect slider action.

3. **Replacement adjusting screws**—All Pickett All-Metal rules are equipped with Telescopic Adjusting Screws. In adjusting your rule, if you should strip the threads on one of the Adjusting Screws, simply "push out" the female portion of the screw and replace with a new screw obtainable from a Pickett & Eckel dealer, or from the Pickett & Eckel factory. We do not recommend replacing only the male or female portion of the screw.

MAINTENANCE OF SLIDE RULE

1. **Operation**—Always hold your rule between thumb and forefinger at the ENDS of the rule. This will insure free, smooth movement of the slider. Holding your rule at the center tends to bind the slider and hinder its free movement.

2. **Cleaning**—Wash surface of the rule with a non-abrasive soap and water when cleaning the scales. If the Cursor Window becomes dulled clean and brighten the surfaces with a small rag and tooth powder.

3. **Lubrication**—The metal edges of your slide rule will require lubrication from time to time. To lubricate, put a little white petroleum jelly (White Vaseline) on the edges and move the slider back and forth several times. Wipe off any excess lubrication. **Do not use ordinary oil as it may eventually discolor rule surfaces.**

4. **Leather Case Care**—Your Leather Slide Rule Case is made of the finest top-grain, genuine California Saddle Leather. This leather is slow-tanned using the natural tanbark from the rare Lithocarpus Oak which grows only in California. It polishes more and more with use and age.
To clean your case and to keep the leather pliable and in perfect condition, rub in a good harness soap such as Propert's Harness Soap.

PART II

FORMULAS USED IN PUMPING LIQUIDS WITH SOLIDS IN SUSPENSION

Slurry treated as Pseudo-Fluid

1. Notation

D = Impeller diameter; inches

g = Acceleration of gravity; ft/sec^2

H = Total head at point designated by subscript; ft-lb/lb

H_C = Total calculated head produced by pump on true fluid; ft-lb/lb

ΣH_L = Summation of head losses; ft-lb/lb

H_P = Total head produced or required by pump; ft-lb/lb

H_{Se} = Additional total head loss due to solids when pumping slurry; ft.-lb/lb slurry

H_{SV} = Net positive suction head; ft-lb/lb

h_f = Friction head; ft-lb/lb/100 ft pipe

h_{st} = Static head; ft-lb/lb

K_e = Entrance loss coefficient; dimensionless

K_{Pf} = Resistance coefficient for valve or pipe fitting; dimensionless

n = Pump shaft and impeller angular velocity; rpm

P = Total pressure at point designated by subscript; lbs/ft^2

P_{atm} = Atmospheric pressure; lbs/ft^2

P_{VP} = Liquid vapor pressure; lbs/ft^2

sp.gr. = Slurry specific gravity; dimensionless

v = Pipeline slurry velocity; ft/sec

$v^2/2g$ = Velocity head (kinetic energy); ft-lb/lb

Z = Elevation head (potential energy); ft-lb/lb

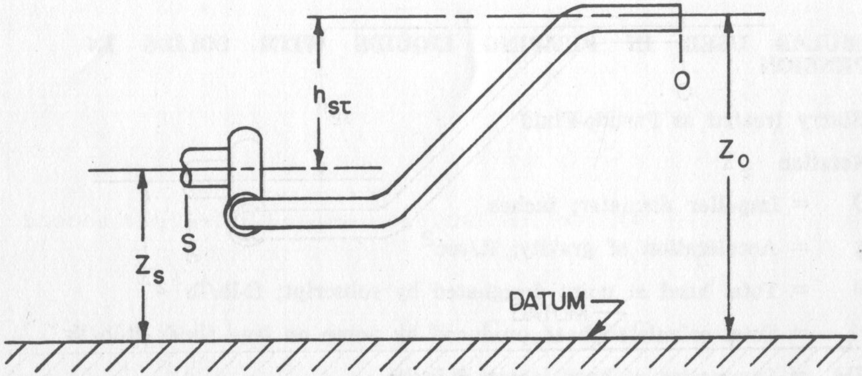
ϕ = Head coefficient of the pump; dimensionless

γ_{SL} = Slurry specific weight (see Preface); lbs/ft^3

γ_L = Liquid specific weight; lb/ft^3

Note: Subscript "S" = pump suction
Subscript "D" = pump discharge

2. Total head "H_P" required by pump



$$H_S + H_P - \Sigma H_{L_{S-O}} = H_O$$

$$H_P = H_O - H_S + \Sigma H_{L_{S-O}}$$

$$H_O = \frac{P_O}{\gamma_{SL}} + \frac{v^2}{2g}_O + Z_O = O + \frac{v^2}{2g}_O + Z_O$$

$$H_S = \frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S$$

$\Sigma H_{L_{S-O}}$ = friction loss + pipe fitting losses

$= h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O$

$$H_P = \left(\frac{v^2}{2g}_O + Z_O\right) - \left(\frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S\right) + \left(h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O\right)$$

$$H_P = -\frac{P_S}{\gamma_{SL}} + \left(\frac{v^2}{2g}_O - \frac{v^2}{2g}_S\right) + (Z_O - Z_S) + h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O$$

$$H_P = -\frac{P_S}{\gamma_{SL}} + \left(\frac{v^2}{2g}_O - \frac{v^2}{2g}_S\right) + h_{s\tau} + h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O$$

For normal dredge service

$\frac{P_S}{\gamma_{SL}}$ = − 22 ft-lb/lb of slurry approximately (slurry sp.gr. 1.2 and 23 in Hg suction vacuum)

$\left(\frac{v^2}{2g}_O - \frac{v^2}{2g}_S\right)$ = 3 ft-lb/lb of slurry approximately (suction pipe larger than discharge pipe and flow at 18 ft/sec pipeline velocity.)

$$H_P = -(-22 \text{ ft-lb/lb of slurry}) + 3 \text{ ft-lb/lb of slurry} + h_{s\tau} + h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O$$

$$H_P = 25 + h_{s\tau} + h_f \times \text{pipeline length}_O + k_{Pf} \times \frac{v^2}{2g}_O$$

3. Total head "H_P" produced by pump

$$H_P = H_C - H_{SE}$$

$$H_C = \frac{u^2}{2g} \times \phi$$

u = impeller peripheral speed in feet per second

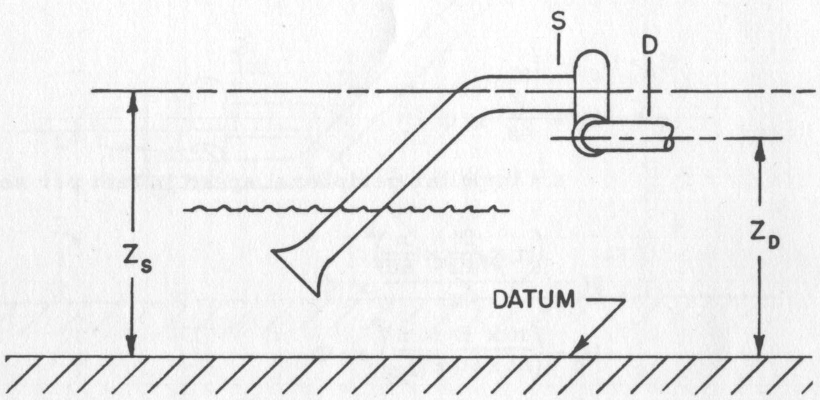
$$H_C = \frac{\left(\pi \times \frac{D}{12} \times \frac{n}{60}\right)^2}{2g} \times \phi$$

$$H_C = \left(\frac{\pi \times D \times n}{12 \times 60 \times \sqrt{2g}}\right)^2 \times \phi$$

$$H_C = \left(\frac{n \times D}{1838.4}\right)^2 \times \phi$$

$$H_P = \left(\frac{n \times D}{1838.4}\right)^2 \times \phi - H_{SE}$$

4. Total head "H_P" produced by pump as calculated from pressure gauges



$$H_P = H_D - H_S$$

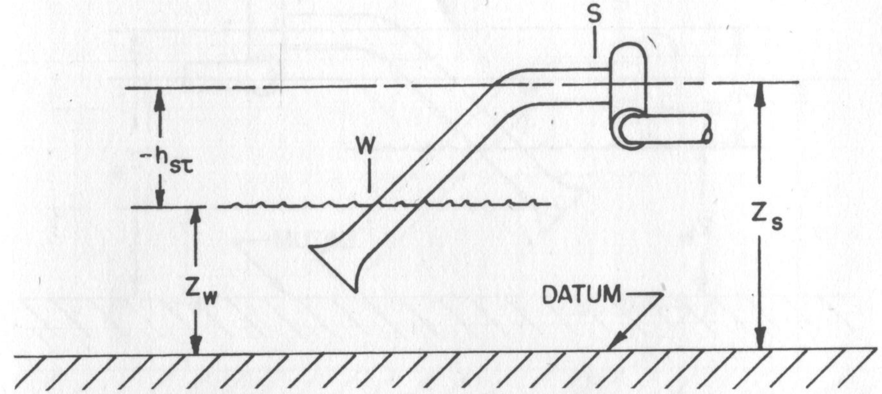
$$H_D = \frac{P_D}{\gamma_{SL}} + \frac{v^2}{2g}_D + Z_D$$

$$H_S = \frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S$$

$$H_P = \left(\frac{P_D}{\gamma_{SL}} + \frac{v^2}{2g}_D + Z_D\right) - \left(\frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S\right)$$

$$H_P = \left(\frac{P_D}{\gamma_{SL}} - \frac{P_S}{\gamma_{SL}}\right) + \left(\frac{v^2}{2g}_D - \frac{v^2}{2g}_S\right) + (Z_D - Z_S)$$

5. Total suction pressure "$\frac{P_S}{\gamma_{SL}}$" available to pump



$$H_S = H_W - \Sigma H_{L_{W-S}}$$

$$H_S = \frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S$$

$$H_W = \frac{P_W}{\gamma_{SL}} + \frac{v^2}{2g}_W + Z_W = 0 + 0 + Z_W = Z_W$$

$\Sigma H_{L_{W-S}}$ = entrance loss+friction loss+pipe fitting losses

$$= k_e \times \frac{v^2}{2g}_S + h_f \times \text{pipeline length}_S + k_{Pf} \times \frac{v^2}{2g}_S$$

$$= h_f \times \text{pipeline length}_S + \frac{v^2}{2g}_S \times (k_e + k_{Pf})$$

$$\left(\frac{P_S}{\gamma_{SL}} + \frac{v^2}{2g}_S + Z_S\right) = (Z_W) - \left[h_f \times \text{pipeline length}_S + \frac{v^2}{2g}_S \times (k_e + k_{Pf})\right]$$

$$\frac{P_S}{\gamma_{SL}} = (-Z_S + Z_W) - \frac{v^2}{2g}_S - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}_S \times (k_e + k_{Pf})$$

$$\frac{P_S}{\gamma_{SL}} = -(Z_S - Z_W) - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}_S \times (1 + k_e + k_{Pf})$$

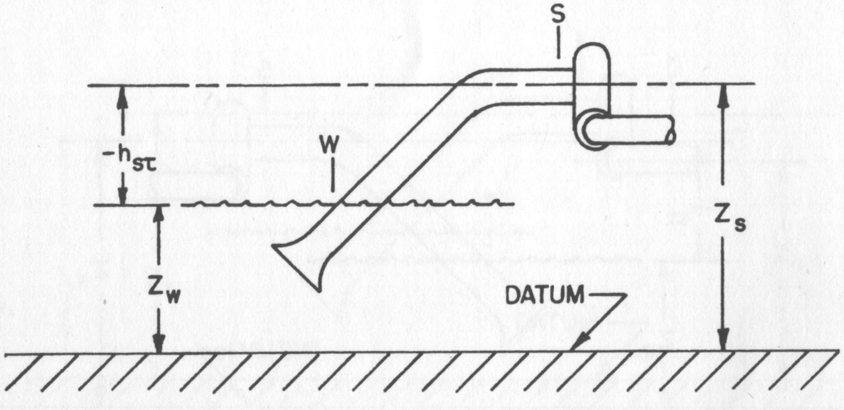
$$\frac{P_S}{\gamma_{SL}} = h_{s\tau} - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}_S \times (1 + k_e + k_{Pf})$$

Note: Units of "$\frac{P_S}{\gamma_S}$" as obtained above are ft-lb/lb of slurry
To convert units:

a. $\frac{P_S}{\gamma_{SL}}$ x sp. gr. slurry = suction pressure in ft H_2O

b. $\frac{P_S}{\gamma_{SL}} \times \frac{\text{sp. gr. slurry}}{1.131}$ = suction pressure in in. Hg

6. Net positive suction head "H_{SV}" available to pump calculated from pipeline arrangement



$H_{SV} = H_S - Z_S - \frac{P_{VP}}{\gamma_{SL}}$ (Basic definition of H_{SV})

$H_S = H_W - \Sigma H_{L_{W-S}}$

$H_W = \frac{P_W}{\gamma_{SL}} + \frac{v^2}{2g}W + Z_W = 0 + 0 + Z_W = Z_W$

$\Sigma H_{L_{W-S}}$ = entrance loss + friction loss + pipe fitting losses

$= k_e \times \frac{v^2}{2g}S + h_f \times \text{pipeline length}_S + k_{Pf} \times \frac{v^2}{2g}S$

$= h_f \times \text{pipeline length}_S + \frac{v^2}{2g}S \times (k_e + k_{Pf})$

$H_S = (Z_W) - \left[h_f \times \text{pipeline length}_S + \frac{v^2}{2g}S \times (k_e + k_{Pf})\right]$

$= Z_W - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}S \times (k_e + k_{Pf})$

$H_{SV} = \left[Z_W - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}S \times (k_e + k_{Pf})\right] - Z_S - \frac{P_{VP}}{\gamma_{SL}}$

$H_{SV} = -(Z_S - Z_W) - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}S\,(k_e + k_{Pf}) - \frac{P_{VP}}{\gamma_{SL}}$

$\frac{P_{VP}}{\gamma_{SL}}$ = vapor pressure (relative pres.) ft-lb/lb slurry

$\frac{P_{VP}}{\gamma_{SL}}$(rel.pres.) = $\frac{P_{VP}}{\gamma_{SL}}$(abs.pres.) $- \frac{P_{atm}}{\gamma_{SL}}$

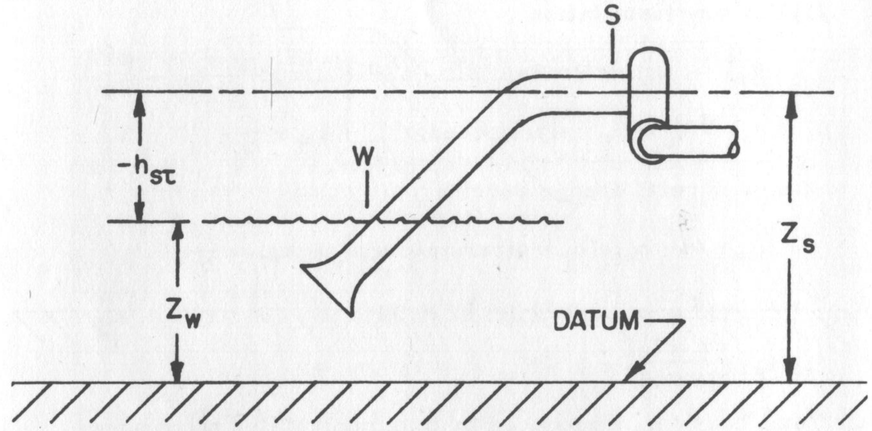
$-h_{ST} = Z_S - Z_W$

$H_{SV} = h_{ST} - h_f \times \text{pipeline length}_S - \frac{v^2}{2g}S \times (k_e + k_{Pf}) - \frac{P_{VP}}{\gamma_{SL}}\text{abs.} + \frac{P_{atm}}{\gamma_{SL}}$

Note: Units of H_{SV} as obtained above are ft-lb/lb slurry. To convert units:

$$H_{SV} \times \frac{\text{sp. gr. slurry}}{\text{sp. gr. liquid}} = H_{SV} \text{ ft-lb/lb of liquid}$$

7. Net positive suction head "H_{SV}" available to pump calculated from pressure gauges



Note: This is the only case in which the units of each item is taken as ft-lb/lb of liquid (true fluid) even though pumping a slurry.

$H_{SV} = H_S - Z_S - \frac{P_{VP}}{\gamma_L}$ (Basic definition of H_{SV})

$H_S = \frac{P_S}{\gamma_L} + \frac{v^2}{2g}S + Z_S$

$\frac{P_{VP}}{\gamma_L}$(rel.pres.) = $\frac{P_{VP}}{\gamma_L}$(abs.pres.) $- \frac{P_{atm}}{\gamma_L}$

$H_{SV} = \left(\frac{P_S}{\gamma_L} + \frac{v^2}{2g}S + Z_S\right) - Z_S - \left(\frac{P_{VP}}{\gamma_L}\text{abs.} - \frac{P_{atm}}{\gamma_L}\right)$

$H_{SV} = \frac{P_S}{\gamma_L} + \frac{v^2}{2g}S - \frac{P_{VP}}{\gamma_L}\text{abs.} + \frac{P_{atm}}{\gamma_L}$

Note: Units of H_{SV} as obtained above are ft-lb/lb of liquid (true fluid).

8. Summation of formulas

A. Total head "H_P" required by pump

(1) For any installation

$$H_P = -\text{Suction Pressure (ft-lb/lb slurry)} + \left(\frac{v^2}{2g}_D - \frac{v^2}{2g}_S\right) + h_{ST} + (h_f \times \text{pipeline length}_D) + k_{Pf} \times \frac{v^2}{2g}_D$$

(2) For normal dredge service

$$H_P = 25 + h_{ST} + (h_f \times \text{pipeline length}_D) + k_{Pf} \times \frac{v^2}{2g}_D$$

B. Total head "H_P" produced by pump

$$(1)\ H_P = \left(\frac{n \times D}{1838.4}\right)^2 \times \phi - H_{SE}$$

C. Total head "H_P" produced by pump calculated from pressure gauges

$$(1)\ H_P = \left(\frac{P_D}{\gamma_{SL}} - \frac{P_S}{\gamma_{SL}}\right) + \left(\frac{v^2}{2g}_D - \frac{v^2}{2g}_S\right) + (Z_D - Z_S)$$

D. Total suction pressure "$\frac{P_S}{\gamma_{SL}}$" available to pump

$$(1)\ \frac{P_S}{\gamma_{SL}} = h_{ST} - (h_f \times \text{pipeline length}_S) - \frac{v^2}{2g}_S (1 + k_e + k_{Pf})$$

E. Net positive suction head "H_{SV}" available to pump calculated from <u>pipeline arrangement</u>

$$(1)\ H_{SV} = h_{ST} - (h_f \times \text{pipeline length}_S) - \frac{v^2}{2g}_S (k_e + k_{Pf}) - \frac{P_{VP}}{\gamma_{SL}}\text{abs} + \frac{P_{atm}}{\gamma_{SL}}$$

Note: $\frac{P_{VP}}{\gamma_{SL}}$ abs = vapor pressure (absolute pres.); ft-lb/lb slurry

$\frac{P_{atm}}{\gamma_{SL}}$ = atmospheric pressure; ft-lb/lb slurry

F. Net positive suction head "H_{SV}" available to pump calculated from <u>pressure gauges</u>

$$(1)\ H_{SV} = \frac{P_S}{\gamma_L} + \frac{v^2}{2g}_S - \frac{P_{VP}}{\gamma_L}\text{abs} + \frac{P_{atm}}{\gamma_L}$$

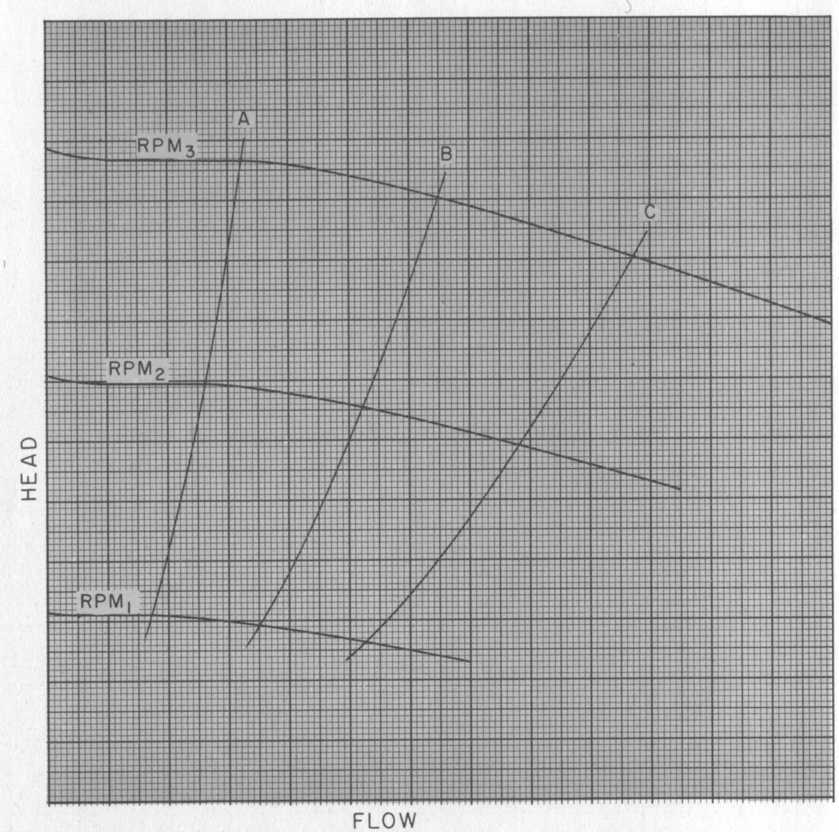
Note: $\frac{P_{VP}}{\gamma_L}$ abs. vapor pressure (absolute pres.); ft-lb/lb liquid

$\frac{P_{atm}}{\gamma_L}$ atmospheric pressure; ft-lb/lb liquid

Note: Above formula is only case in which the units of each item is taken as ft-lb/lb of liquid (true fluid) even though pumping a slurry.

PART III - CHARTS

CHART NO. I—Pump characteristic head-capacity curve



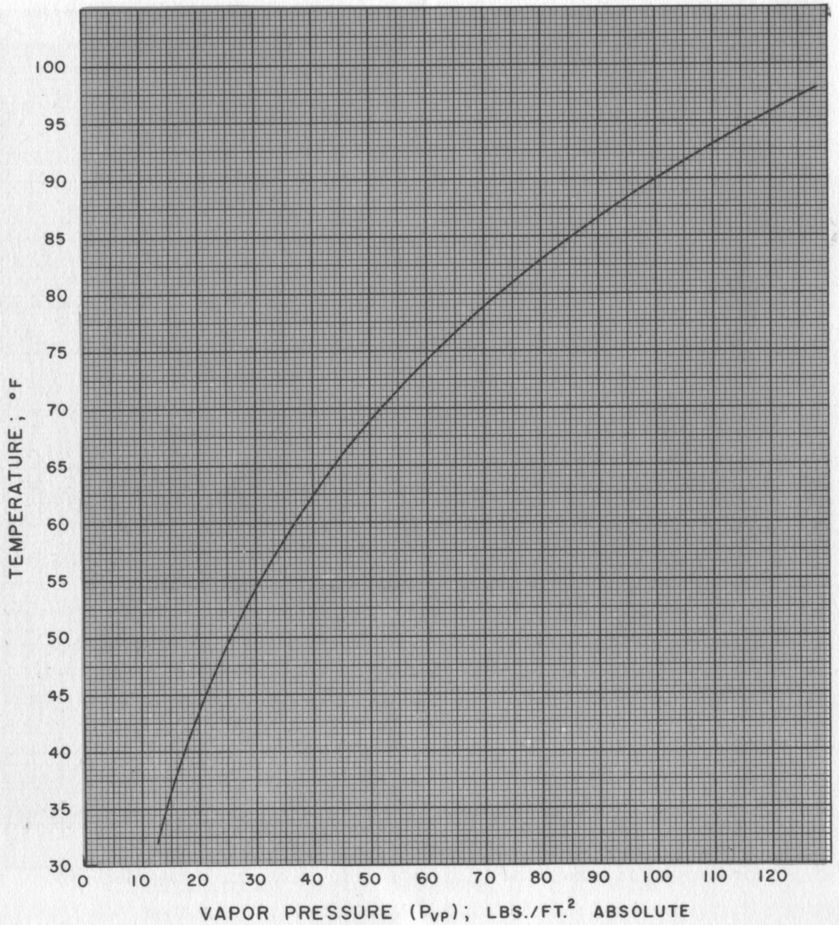
The variation of head, capacity, and brake horsepower with changes of speed (RPM) follows rules known as the affinity laws. The laws are expressed by the following equations:

$$\frac{\text{Flow}_1}{\text{Flow}_2} = \frac{\text{RPM}_1}{\text{RPM}_2} \qquad \frac{\text{Head}_1}{\text{Head}_2} = \frac{\text{RPM}_1^2}{\text{RPM}_2^2} \qquad \frac{\text{BHP}_1}{\text{BHP}_2} = \frac{\text{RPM}_1^3}{\text{RPM}_2^3}$$

Points along lines A, B, and C are connected by the affinity laws and are said to be corresponding or homologous points which have the same efficiency, specific speed, and ϕ (head coefficient).

The hydraulic slide rule may be used with a characteristic head-capacity curve to calculate any point (head and flow) or any speed (RPM) by the use of a corresponding ϕ (calculated from a given head-capacity curve).

CHART NO. II—Vapor pressure (absolute) of water vs. temperature—30°F to 90°F

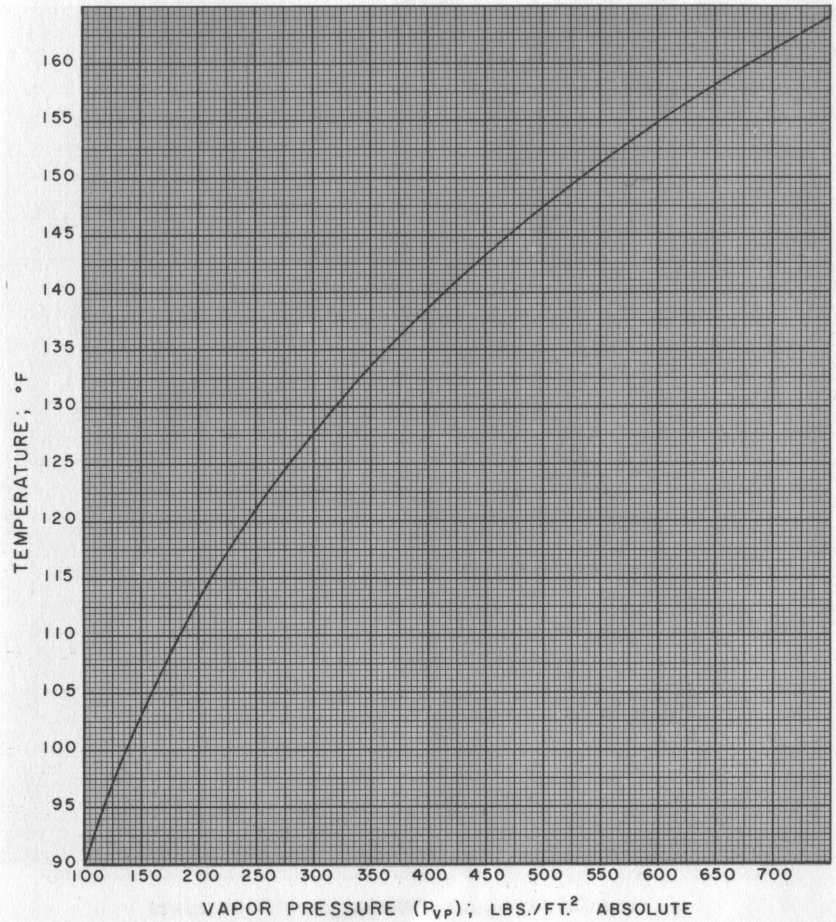


NOTE: To obtain vapor pressure head

$$\frac{P_{VP}}{\gamma_L} = \frac{\text{vapor pressure (absolute) lbs./ft.}^2}{\text{sp. gr. liquid} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. liquid (absolute)}$$

$$\frac{P_{VP}}{\gamma_{SL}} = \frac{\text{vapor pressure (absolute) lbs./ft.}^2}{\text{sp. gr. slurry} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. slurry (absolute)}$$

CHART NO. III—Vapor pressure (absolute) of water vs. temperature—90°F to 162°F

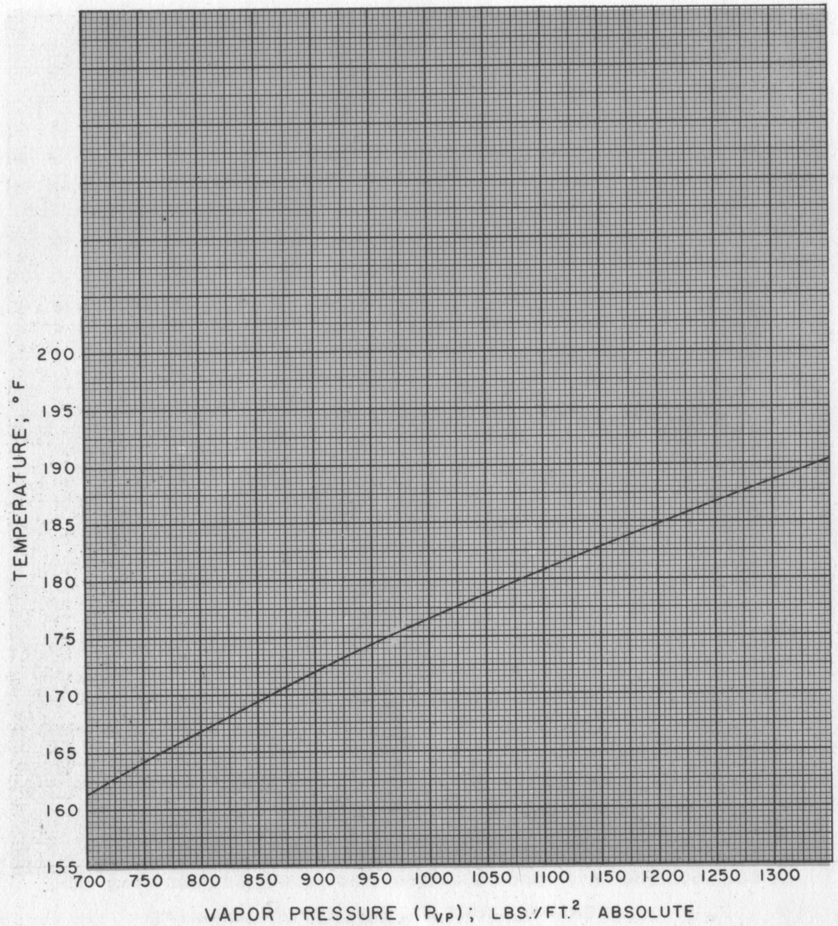


NOTE: To obtain vapor pressure head

$$\frac{P_{VP}}{\gamma_L} = \frac{\text{vapor pressure (absolute) lbs./ft}^2}{\text{sp. gr. liquid} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. liquid (absolute)}$$

$$\frac{P_{VP}}{\gamma_{SL}} = \frac{\text{vapor pressure (absolute) lbs./ft.}^2}{\text{sp. gr. slurry} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. slurry (absolute)}$$

CHART NO. IV—Vapor pressure (absolute) of water vs. temperature—162°F to 190°F

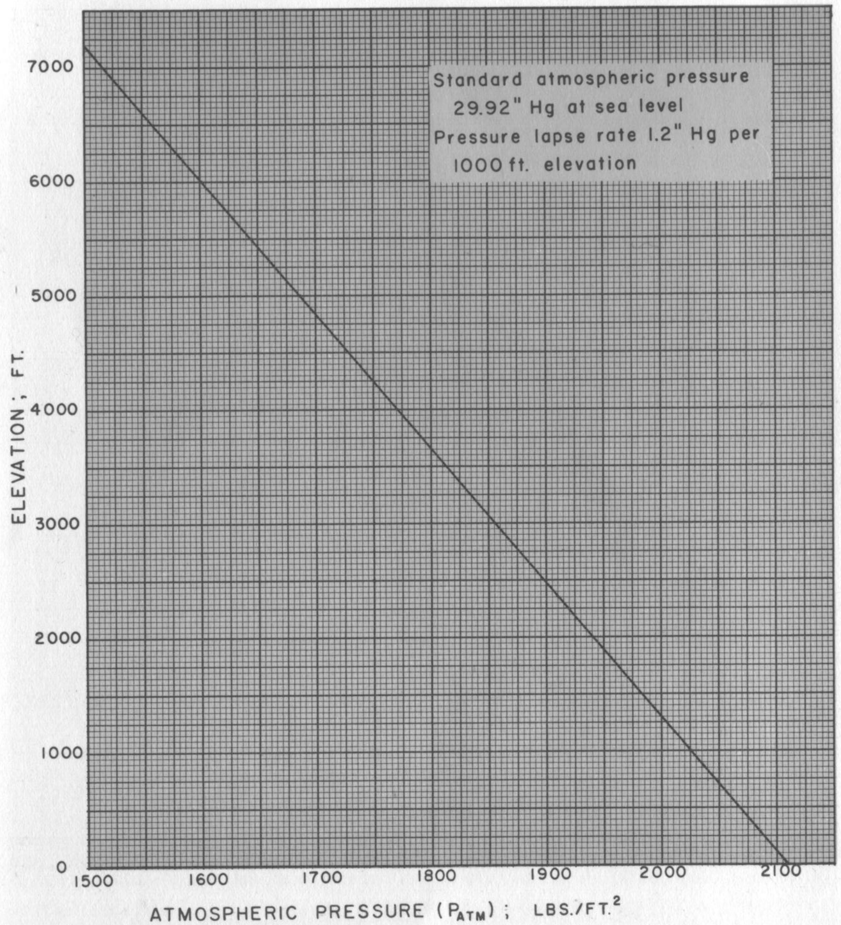


NOTE: To obtain vapor pressure head

$$\frac{P_{VP}}{\gamma_L} = \frac{\text{vapor pressure (absolute) lbs./ft.}^2}{\text{sp. gr. liquid} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. liquid (absolute)}$$

$$\frac{P_{VP}}{\gamma_{SL}} = \frac{\text{vapor pressure (absolute) lbs./ft.}^2}{\text{sp. gr. slurry} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. slurry (absolute)}$$

CHART NO. V—Atmospheric pressure vs. elevation



NOTE: To obtain atmospheric pressure head

$$\frac{P_{ATM}}{\gamma_L} = \frac{\text{atmospheric pressure ; lbs./ft.}^2}{\text{sp. gr. liquid} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. liquid}$$

$$\frac{P_{ATM}}{\gamma_{SL}} = \frac{\text{atmospheric pressure ; lb./ft.}^2}{\text{sp. gr. slurry} \times 62.3 \text{ lbs./ft.}^3} \text{ ; ft.-lb./lb. slurry}$$