HYDRAULIC SLIDE RULE

- **INSTRUCTIONS**
- **FORMULAS** (AS APPLIED TO A LIQUID-SOLIDS MIXTURE)

by

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PREFACE

The following manual will give a brief explanation in the use of all scales appearing on the GIW Hydraulic Slide Rule. In each type of problem, pertinent formulas will be given, scales pointed out, and two example problems worked.

The approach used in all definitions and calculations is based on slurry (liquid-solids mixture) being treated as a pseudo-fluid. Considering the flowing mixture as a single-phase pseudo-fluid is a reasonable simplification if the transported solids are in suspension without bed deposits in the pipe. 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 slurry level in the can.

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

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

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

e. Slurry s.g. = ratio of net weights from (d) above.

Prior to using the slide rule for the solution of problems in which liquid-solids mixtures are visualized as pseudo-fluids, definition of the terms C, H_{se} , and E_{se} is required. C is a constant appearing in the empirical equation developed by Hazen & Williams for calculating friction loss. H_{se} is head loss and E_{se} is efficiency loss due to the effect of solids in suspension. A characteristic head-capacity pump-performance curve is relative to performance of a pump on clear water at 60°F.

Hazen & Williams' empirical friction loss equation was intended for use with clear water and the constant C was 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 also account for the effects of foreign particles. When pumping slurries the pipe wall is polished by the abrasive slurry; thus, a variation of C is largely the effect of solids upon the flow pattern. Since the mechanics of solids transport is not highly developed, a 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 units of feet of slurry, the effect of solids concentration is reduced.

H_{se} is the difference between head produced when pumping clear water at 60°F and head that is actually produced when pumping a slurry (units ft-lb/lb of pseudo-fluid). As a point of interest, in most cases, solids passing through a pump increase pressure of the liquid instead of detracting from it. This is possible since 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. If solids particles are very small in the micron range as with clays, H_{se} and E_{se} approach zero. If the concentration of clay in a slurry is excessive, there will be a head loss and efficiency loss by the pump due to viscosity. The presence of a moderate percentage of clays has the helpful effect that a lesser degree of turbulence (hence a lower pipeline velocity) is necessary to keep large coarse solids in suspension in a horizontal pipeline. The fall velocity of coarse solids is reduced in a more viscous fluid (water-clay mixture).

The above C, H_{se} , and E_{se} vary depending on the slurry concentration, liquid viscosity, and particle size, shape, and specific weight. Approximate values of C, H_{se} , and E_{se} can be supplied by GIW if a customer will furnish a thorough description or sample of the solids and the desired slurry concentration. Results of tests in the GIW hydraulic laboratory, field tests, and knowledge gained through more than 50 years experience in the field of pumping liquids with solids in suspension are utilized by our engineers in estimating reasonable values of C, H_{se}, and E_{se}. When required, laboratory tests or field tests can be performed on a particular slurry for a more accurate determination of C, H_{se}, and E_{se}.

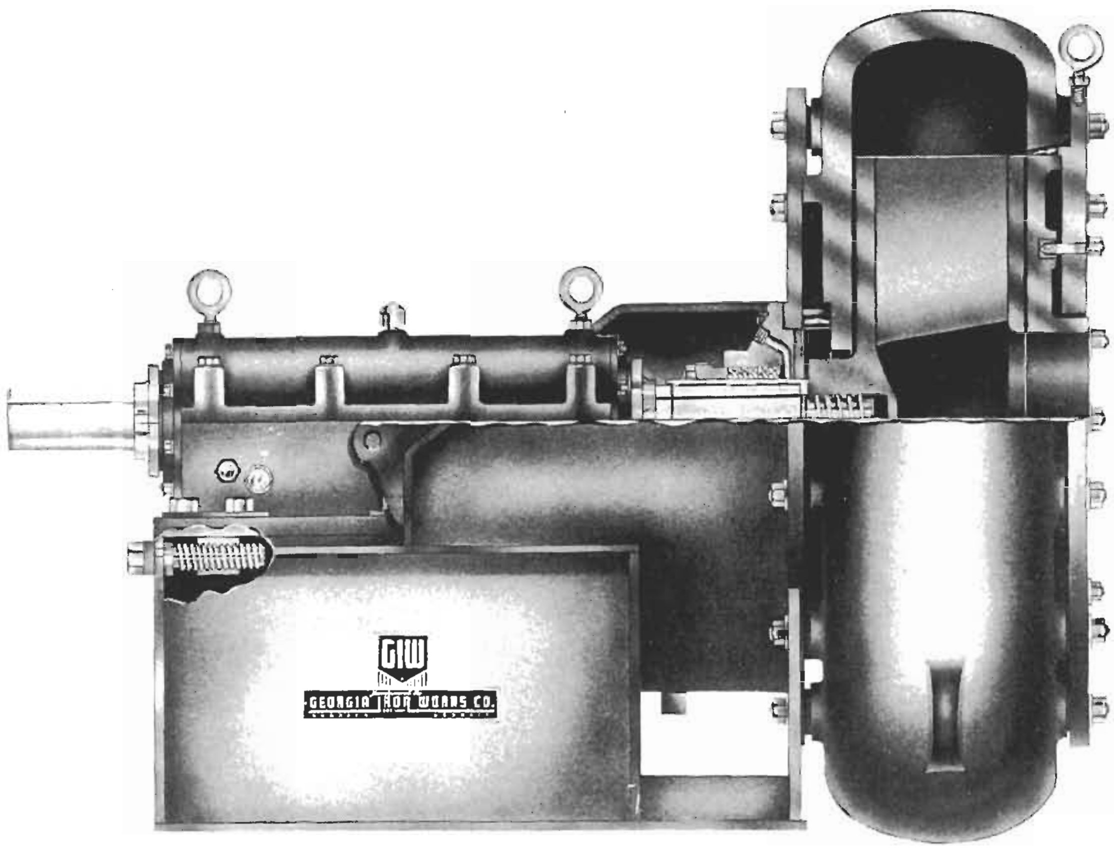
Assuming that the forward velocities of solids and liquid are equal, velocity head ($v^2/2g$) is in units of ft of slurry (ft-lb/lb of pseudo-fluid). If the solids are assumed to be in suspension, static head or the difference in liquid elevation which a pump must overcome is in units of ft of slurry (ft-lb/lb of pseudo-fluid) as measured. Finally, the value k (resistance coefficient for valve or pipe fitting) should be taken from the Hydraulic Institute Pipe Friction Manual. Head loss for fittings as calculated by the above method is in units of ft of slurry (ft-lb/lb of pseudo-fluid).

Gallons per minute referred to in this manual and used on the hydraulic slide rule is US GPM. To obtain Imperial GPM divide US GPM by 1.201, or use the hydraulic slide rule conversion arrows as outlined in this manual.

NOTES

GIW PUMPS

Workhorse of Industry



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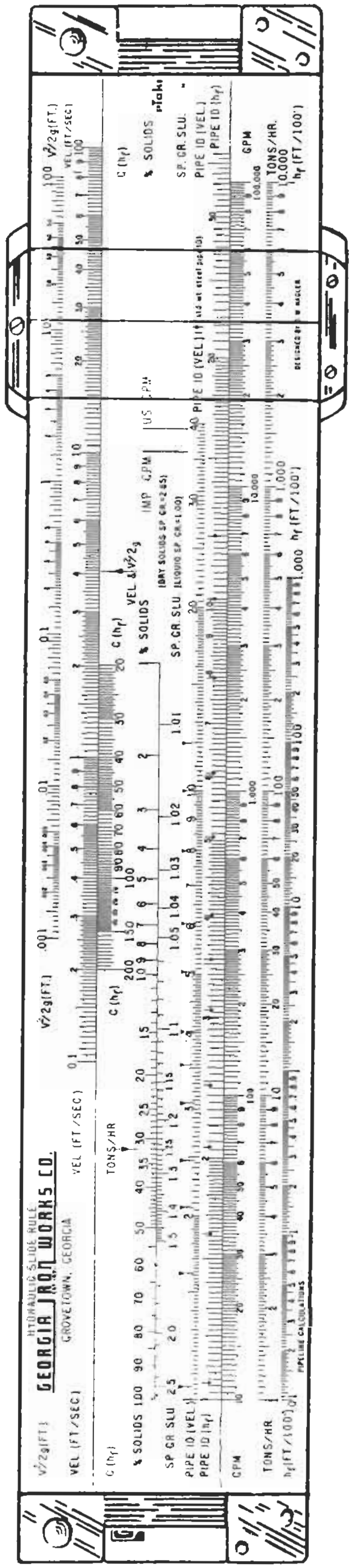
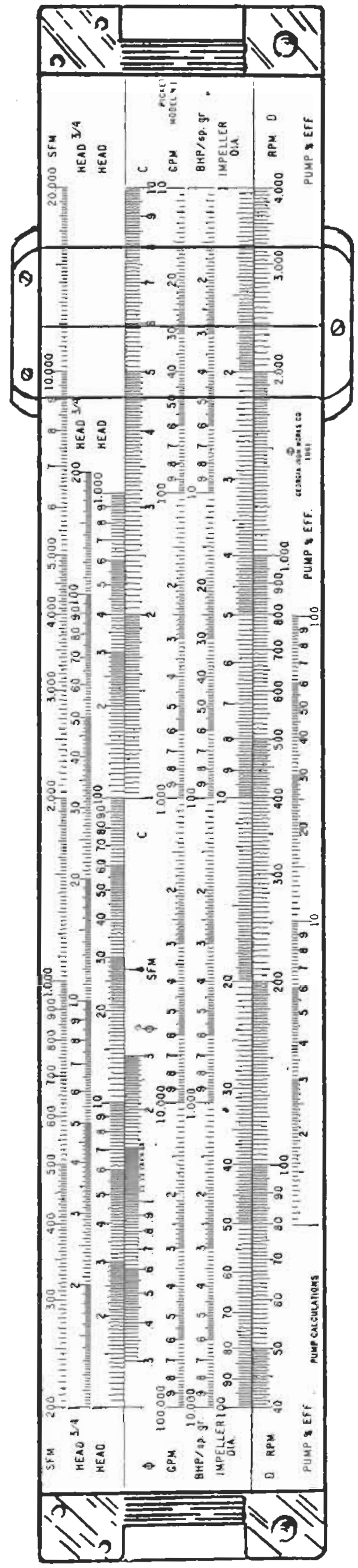


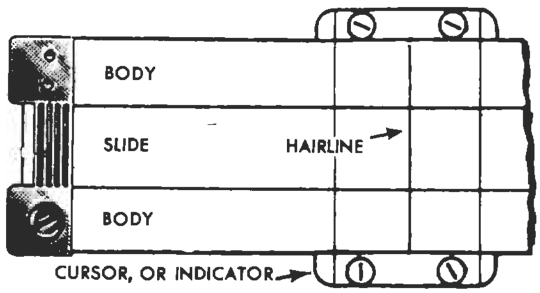
Pipeline Calculations



Pump Calculations

INTRODUCTION

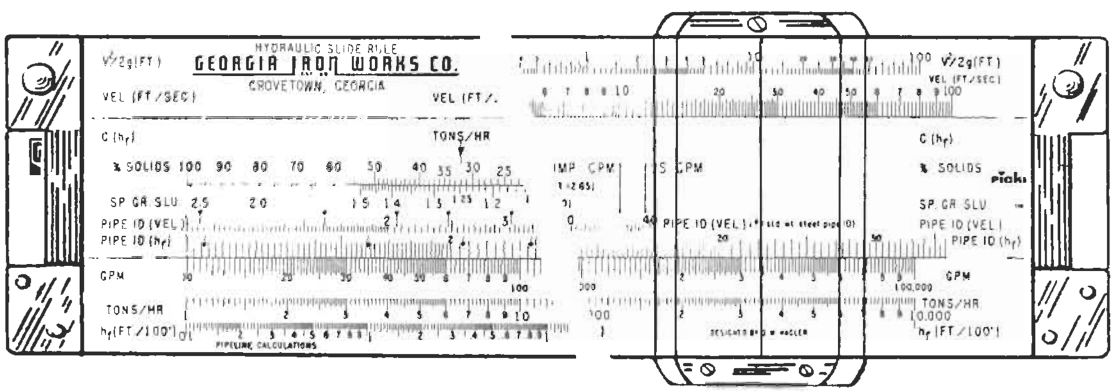
The slide rule consists of three parts: (1) the stator (upper and lower bars); (2) the slide; (3) the cursor or indicator.



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 pseudo-fluid
Vel.=Pipeline liquid or slurry velocity; ft/sec
C (h_f)= Hazen-Williams constant.
% 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; dimensionless
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 pseudo-fluid/100 ft. pipe.
Note: US GPM converted to Imperial GPM by use of arrows

2. Pipeline Friction Loss h_f

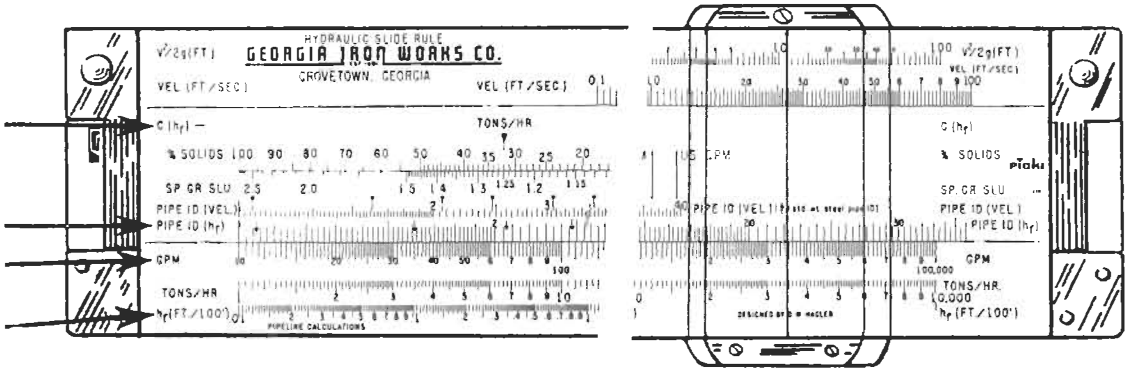
Formula:

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

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. pipe.

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.

$$\frac{14.4 \text{ ft. slurry / 100 ft. pipe x 1.142 sp. gr.}}{2.31 \text{ ft. } H_2O\text{/psi}} = 7.12 \text{ psi/100 ft. pipe}$$

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. pipe
Pressure loss=2.86 psi/100 ft. pipe

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

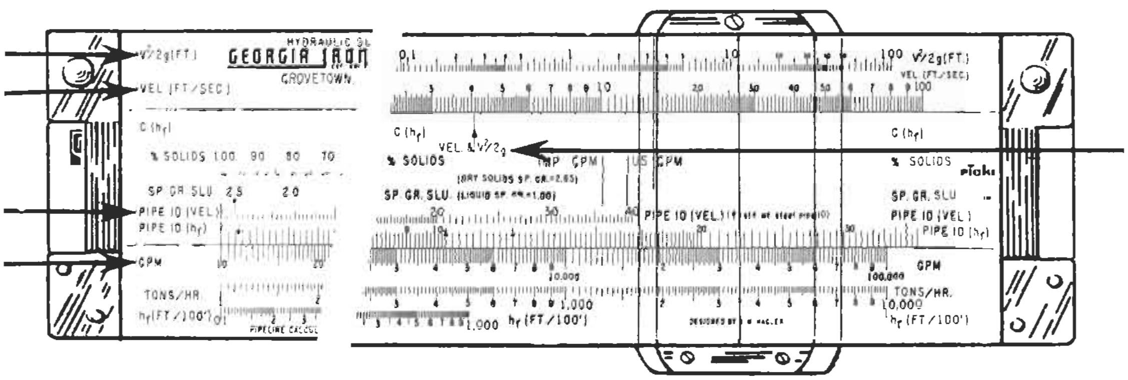
Formula:

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

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

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 (tons/hr.)**

Formula:

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

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.

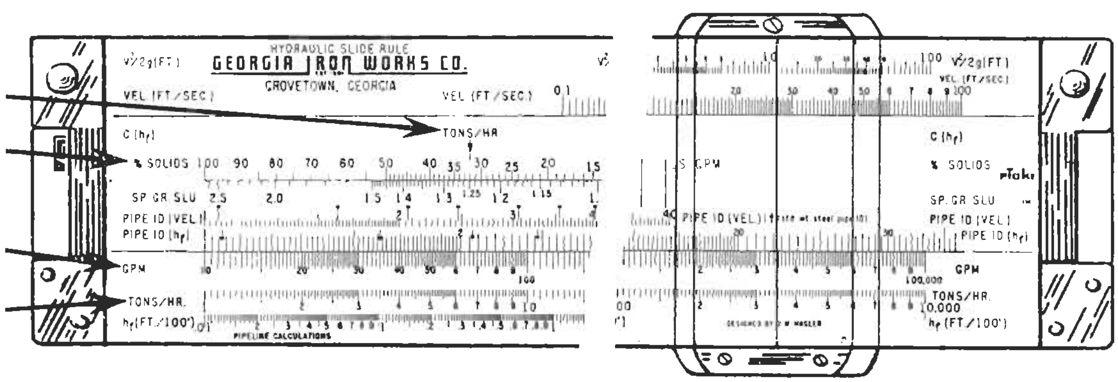
Note: To use the above formula for any sp. gr. solids or liquid, the folowing formula is helpful in determining the slurry sp. gr. when the slurry density (% solids by weight) is known:

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

(% 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
Per cent 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.

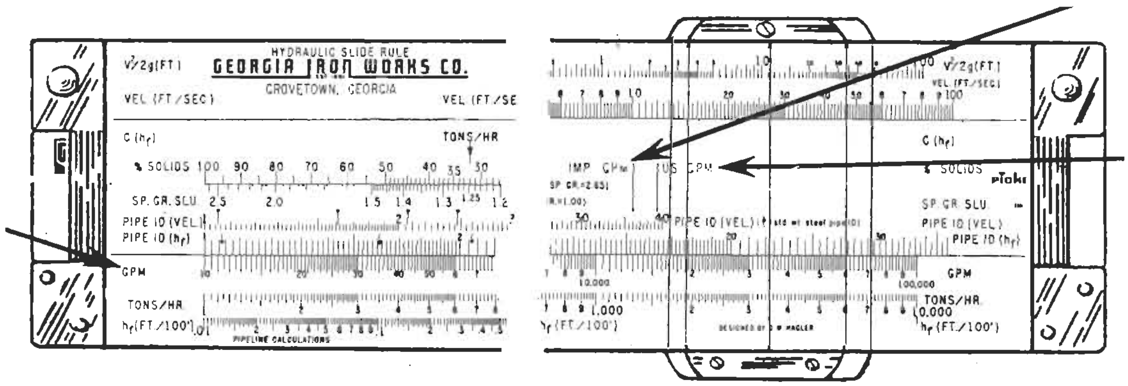
5. Conversion of US GPM to Imperial GPM

Formula: $\text{Imperial GPM} = \dfrac{\text{US GPM}}{1.201}$

Note: The GIW hydraulic slide rule is based on US GPM. All problems must be worked on the basis of US GPM.

Scales necessary for converting US GPM to Imperial GPM or the reverse are as follows:

GPM, and Imperial GPM and US GPM conversion arrows.



Example problems:

A. Given:
Flow=2800 US GPM

Find:
Flow in units of Imperial GPM

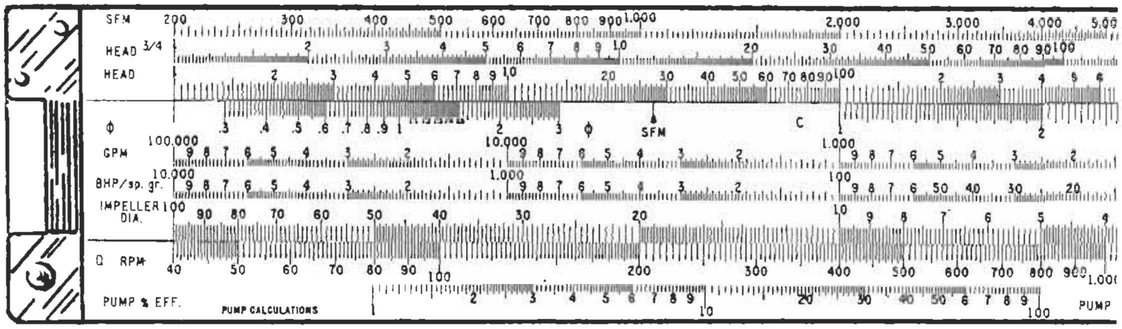
Place the hairline over the flow of 2800 gpm. Now move the slide so as to place the US GPM arrow under the hairline. Without moving the slide, move the hairline over the arrow Imp. GPM and read the resulting flow of 2330 gpm in units of Imperial GPM.

B. Given:
Flow=11,000 Imp. GPM

Find:
Flow in units of US GPM
Answer:
Flow = 13,200 US GPM

PUMP CALCULATIONS

1. Designation of Scales Used for Pump Calculations



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

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

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

ϕ =Head coefficient of the pump.

C=Standard slide rule C scale for use in multiplication and division

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

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

Note: The above D denotes that the RPM scale is also used as a standard slide rule D scale in conjunction with scale C above for multiplication and division.

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 by ϕ so as to account for impeller vane and pump casing design.

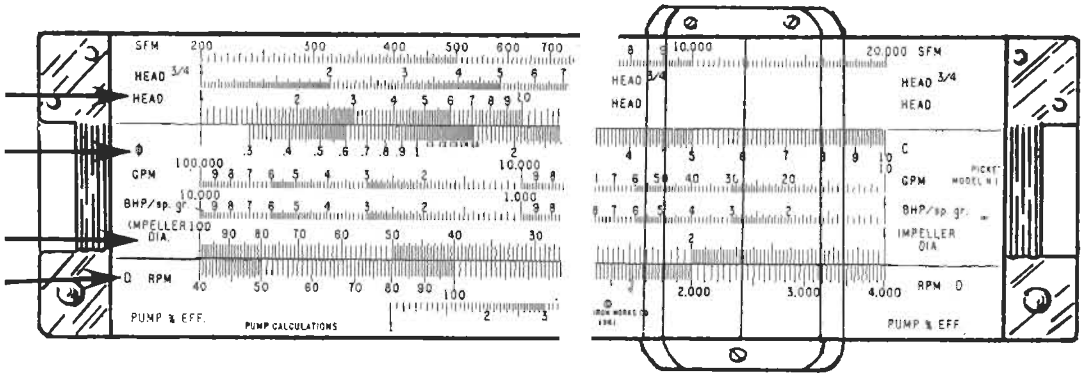
Note: The above formula and the slide rule obtain head of a true fluid. When applied to a slurry, this head does not take into account the additional head loss due to solids. This is because a pump will not produce as much head when pumping a slurry or pseudo-fluid as it would on a true fluid of the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

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

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 and Head



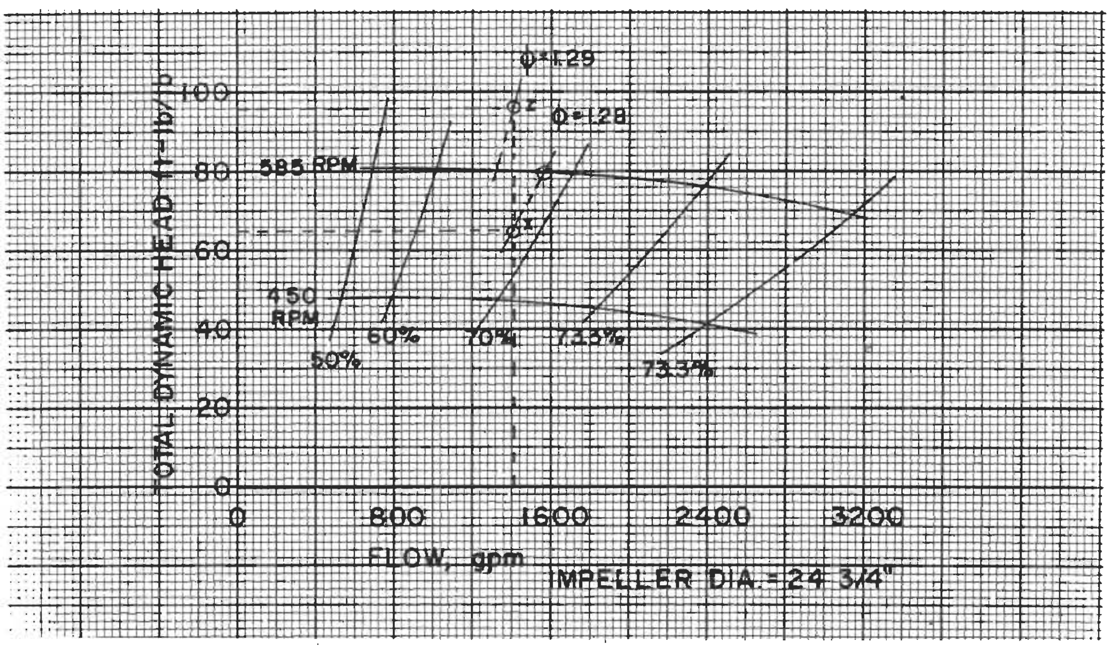
Example problems:

A. Given:

Performance curve below
Impeller dia.=24.75" in dia.
Head (Point x)=65.0 ft-lb/lb
(true fluid)
Flow (Point x)=1400 gpm

Find:

Pump rpm at point X



To obtain pump rpm at point x, it is first necessary to determine the value of ϕ at point x. ϕ parameters parallel efficiency parameters, therefore, from point x parallel the 70% efficiency parameter to intercept head-capacity curve 585 rpm at point Y (79.5 ft-lb/lb head at 1550 gpm). It is possible to determine ϕ at point Y by first placing the hairline over 585 rpm. Move the slide so as to put 24.75 inches on the impeller diameter scale under the hairline. Without moving the slide, move the hairline over 79.5 ft-lb/lb head and read the value of ϕ at point Y under the hairline. The answer is $\phi = 1.28$.

Since Φ parameters parallel efficiency parameters, the value of Φ at point x would be the same as at point Y which was determined above to be 1.28. To determine rpm at point x, place the hairline over 65.0 ft-lb/lb head. Now move the slide so as to put Φ of 1.28 under the hairline. Without moving the slide, move the hairline over 24.75 inches impeller diameter and read the resulting pump rpm under the hairline. The answer is 529 rpm.

B. Given:

Performance curve above
Impeller dia=22"
Head (Point z)=96.0 ft-lb/lb (true fluid)
Flow (Point z)=1400 gpm
H_{se} =5 ft-lb/lb (head loss due to solids)

Find:

RPM at point z
Head (produced by pump on slurry at point z)

Answer:

RPM at point z=720 rpm
Head=91.0 ft-lb/lb (pseudo-fluid or slurry)

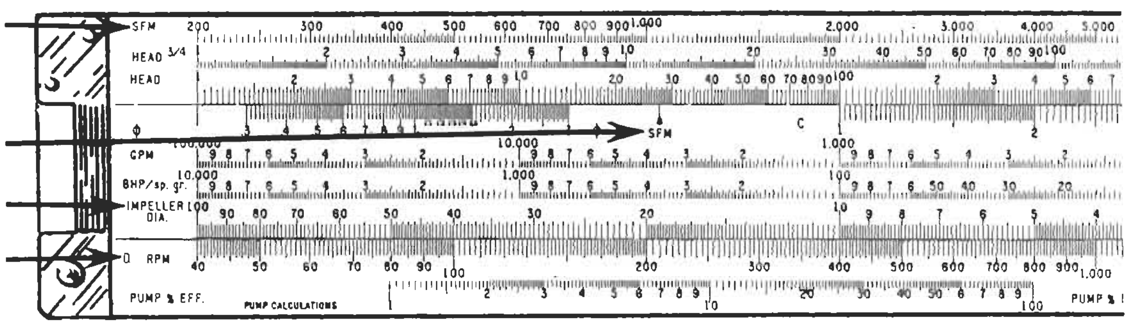
3. **Impeller peripheral speed in surface feet per minute (SFM)**

Formula:

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

Scales necessary for determining SFM are as follows:

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



Example problems:

A. Given:

Impeller dia.=24.75"
RPM=900 rpm

Find:

SFM

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:

Impeller dia.=39"
RPM=585 rpm

Find:

SFM

Answer:

SFM=5,970 ft/min.

4. **Brake horsepower (BHP) divided by slurry specific gravity (sp. gr.)**
Formula:

$$BHP = \frac{\text{Head} \times GPM \times \text{sp. gr.}}{3962.5 \times \text{Eff. (decimal)}}$$

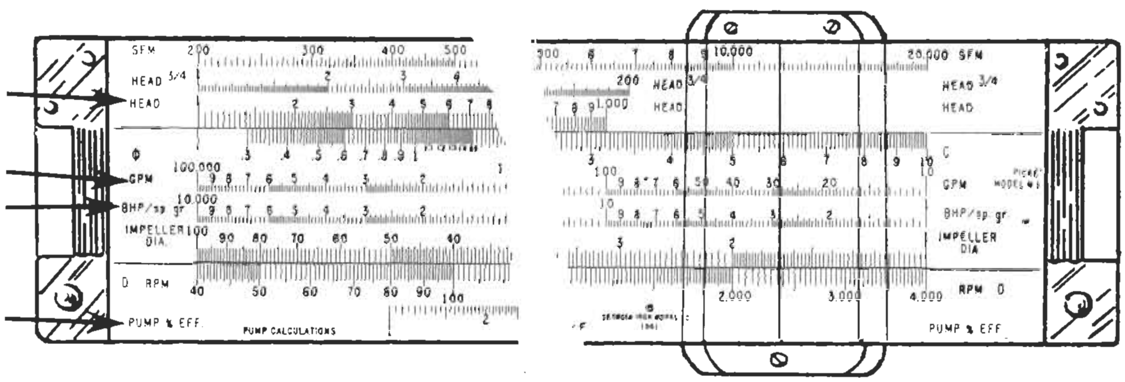
$$\text{BHP/sp. gr.} = \frac{\text{Head x GPM}}{3962.5 \text{ x \% Eff.}}$$

Note: If the above formula is applied where pumping a slurry, the head must be in units of feet of slurry (ft-lb/lb of pseudo-fluid). If pump head is 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.

Note: If the above formula is applied when pumping a slurry, it is necessary to know "E_{sa}" which is efficiency loss due to solids. The characteristic head capacity performance curve gives pump efficiency only on a true fluid.

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 (on slurry)
Flow=2800 gpm
Pump % Eff.=70% (on slurry)
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 (on slurry)
Flow=11,000 gpm
Pump % Eff.=68% (on slurry)
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=1016 hp

5. Head ¾ used in calculating specific speed

Formula:

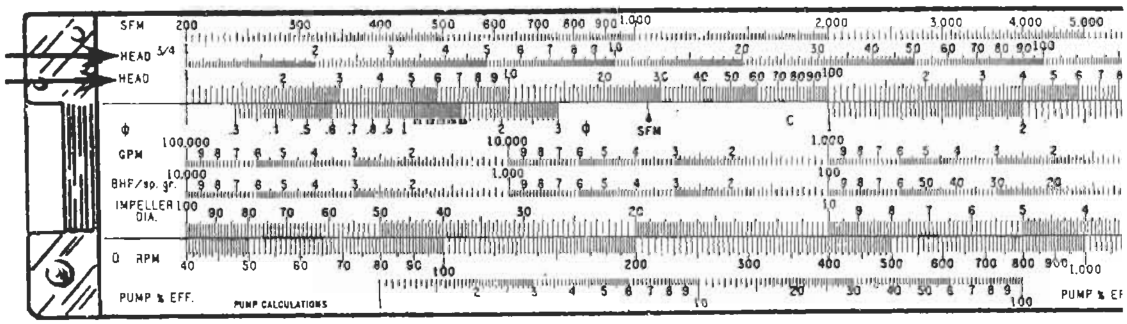
$H^{3/4}$ is used in calculating specific speed.

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

Note: Specific speed is a correlation of pump capacity, head, and speed at optimum efficiency, which classifies pump impellers with respect to their geometric similarity.

Scales necessary for determining Head ¾ are as follows:

Head and Head ¾



Example problems:

A. Given:

Head=188 ft-lb/lb true fluid

Find:

Head ¾

To obtain Head ¾ , set the hairline over 188 on the Head scale and read the resulting Head ¾ under the hairline. The answer is 50.8.

B. Given:

Head=197 ft-lb/lb true fliud

Find:

Head ¾

Answer:

Head ¾ =52.6

6. Multiplication and Division

Multiplication and division may be performed as with any standard slide rule by using scale C in conjunction with scale D RPM.

ADJUSTMENT OF SLIDE RULE

Each rule is accurately adjusted before it leaves the Pickett 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 dealer, or from the Pickett 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 Properts' Harness Soap.