DETERMINATION OF ROD GUIDE ERODIBLE WEAR VOLUME

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Introduction

Rod guides used to centralize sucker rods inside tubing have evolved dramatically over the past 20 years. The primary function of a rod guide is to extend the life of the production equipment by preventing metal-to-metal contact. Basically, the portion of a rod guide between the largest O.D. on the rod string and the I.D. of the tubing is all that can prevent the damaging metal-to-metal contact. This protective volume of the rod guide is often referred to as erodible wear volume (EWV). It is an important indicator of rod guide performance.

A properly designed sucker rod string with strategically located rod guides can be economically justified in many situations. One way to evaluate the investment is by the amount of EWV. Unfortunately, EWV can be defined in a variety of ways and a lack of standardization creates confusion when attempts are made to compare the EWV of one rod guide with that of another.

The definition of EWV has evolved since it was first introduced in 1986. The original definition, which will be referred to as Gross EWV, is the amount of rod guide material outside the O.D. of the sucker rod coupling. It is a simple, easy to measure index. Consequently, it is not prone to measurement or calculation errors. However, Gross EWV neglects the effects of rod guide geometry. Initially this was not a problem because the geometry of the few rod guides on the market were very similar. Therefore, Gross EWV did an adequate job as an indicator.

The more recent definition, which will be referred to as Net EWV, is the amount of rod guide material that will erode before the sucker rod coupling contacts the tubing. Net EWV is a more difficult concept and prone to errors in measurement. It is virtually impossible to calculate without sophisticated computer modeling software. However, Net EWV does account for rod guide geometry. It is more representative of true protection and it is a concept that needs to be developed in light of all the new rod guides that are evolving today.

The primary objective of this paper is to compare Gross and Net EWV and to suggest industry standards for measuring both. Unless standards are adopted, EWV as an index will continue to be confusing to the industry. One important point to remember is that no definition of EWV really means anything unless the rod string is continuously rotated and the rod guides wear evenly.

Discussion

Net EWV varies with the rod guide cross sectional profile and the offset between the centerline of the sucker rod and tubing. Values can vary greatly depending on design. For example, consider an extreme example of a rod guide with only two (2) fins that are 180° apart, as shown in **FIGURE No. 1**. Gross EWV is depicted in **FIGURE No. 2**. By definition, all material external to the coupling is Gross EWV. For this design, Gross EWV is arbitrarily set equal to 1. **FIGURE No. 3** shows the same rod guide. It is evident the coupling will make metal-to-metal contact with the tubing long before the Gross EWV is gone. Net EWV is shown in **FIGURE No. 4**. Relative to a Gross EWV of 1, this same design would have a Net EWV of only 0.19.

The greatest variation between Gross and Net EWV will be for a rod guide with one fin. In this case, Net EWV is zero. At the other end of the spectrum is a true cylinder. In this case, Gross and Net EWV are equal. In no case can Net EWV be greater than Gross EWV. **FIGURES No. 5** through **No. 8** show-the Gross and Net EWV comparisons for rod guides with of one, three, and four fins plus a true cylinder.

Rotation of the rod guide by a rod rotator is required to achieve any type of uniform wear pattern. Gross EWV assumes uniform wear for 360° rotation. Net EWV only assumes uniform wear between each set of adjacent fins. Wear patterns observed in the field more closely resemble those of Net EWV than Gross EWV. In theory the rod rotator should produce uniform wear for all rod guides. However, due to variations in deviation, fluid dynamics, rod string torque, etc., very few wear patterns are exactly the same. It is unlikely that any two wells will produce identical wear patterns. In fact, different zones in the same well can each produce unique wear patterns. Consequently, there is no universal EWV.

Measurement Methods

The determination of EWV by the measurement method requires the use of test equipment, special fixtures, and "as-molded" rod guides. The "as-molded" rod guide is submersed in water. Displacement is recorded. The rod guide is machined according to the type of EWV being measured and then submersed again. The final displacement of water is subtracted from the original displacement and the difference is the EWV for that rod guide. The variables associated with this method are confined to the water absorption characteristic of the rod guide material, and machining accuracy. Consequently, there is not much opportunity for operator error.

Calculation Methods

The calculation method utilizes note worthy 3-D, computer generated, mathematical modeling software to determine EWV. Manual calculation of EWV was a viable method in the early stages of rod guide development when designs consisted of very simple geometry. However, with the advent of complex shapes, splined surfaces and transition zones between these unique

geometries, manual calculation has proven to be time consuming and extremely difficult. Calculations are frequently subjected to individual interpretation. The type of software required must be capable of creating a true 3-D model of the rod guide. The term "note worthy" is used here to describe software packages that are capable of linking the 3-D model with a CAM (Computer Aided Machining) package to produce the actual mold for the rod guide. One such software package is Pro-Engineering by Parametric Technology. However, errors are still inherent because actual rod guides are rarely molded to the exact dimensions of the 3-D model. Models are usually generated from mold dimensions.

Recommended Standard Procedure

The following procedure is recommended as a standard for determination of EWV.

SECTION 1: Scope

1.1 Coverage. This procedure covers the definitions and methods of determining Erodible Wear Volume of symmetrical rod guides that are installed or molded concentrically on sucker rods.

1.2 Codes, Specifications, and Standards. Each code, specification, or standard referenced herein shall be the latest edition or supplement in effect at the time the erodible wear volume of the rod guide is determined.

1.3 Definitions

Rod Guide: A component or an assembly of parts designed to prevent the sucker rod coupling from contacting the inside surface of production tubing

EWV: Erodible Wear Volume

Gross EWV: The total volume of material a single rod guide design possesses external of the published outside diameter of the coupling utilized, full size or slim hole. Any bending moments, misalignment between the rod guide and coupling, and the rod guide profile are neglected.

Net EWV: The volume of material a single rod guide design possesses external of the published outside diameter of the coupling utilized, full size or slim hole, that prevents the coupling from contacting the production tubing, taking into account the rod guide profile and offset between the centerlines of the sucker rod and tubing. Any bending moments and misalignment between the rod guide and coupling are neglected.

Measurement Method: The determination of either Gross or Net EWV by mechanically removing the corresponding portion of the rod guide and comparing the "eroded" rod guide's displaced volume of water to that of the "as-molded" rod guide.

Calculation Method: The determination of either Gross or Net EWV by utilizing note worthy 3-D, computer generated, mathematical modeling software.

Ring Gauge: A steel cylinder, whose inside diameter is equal to the drift diameter of API Specification 5CT External Upset Tubing, outside diameter is equal to the actual outside diameter of External Upset Tubing, and length is equal to 12 in. See **FIGURE No. 12.**

SECTION 2: General

2.1 All rod guide designs must be documented with a detailed drawing.

2.2 All specimens of the rod guide design for which Gross or Net EWV are being determined by the measurement method must pass completely through the corresponding ring gauge, in a single direction, without becoming lodged in the ring gauge.

2.3 All cross sections of the rod guide design for which Gross or Net EWV are being determined by the calculation method must lie totally within a circle whose diameter is equal to the drift diameter of the tubing and concentric with the sucker rod.

2.4 Improper machining or preparation of test specimens and inaccurate 3-D models may give erroneous results. Care should be exercised to assure good workmanship and modeling. Improperly machined specimens and flawed models should be discarded.

2.5 Surface defects in the measurement method specimens may also affect results. If any test specimen develops voids, nicks or grooves during the procedure, these imperfections must be filled with a water resistant material and the surface sanded smooth to reflect the proper geometry before displacement measurements are performed. Any test specimen that fails due to mechanical reasons such as failure during machining, improper specimen preparation, or movement of the guide relative to the rod must be discarded.

SECTION 3: Measurement Method

3.1 Required Equipment:

(a) Minimum of two (2) rod guide specimens each for Gross and Net EWV, as molded, with approximately 3.5 inches of exposed sucker rod on both ends as shown in **FIGURE No. 9(A)**.

(b) Manual Engine Lathe

(c) Displacement apparatus (See **FIGURE No. 10**)

(d) Fixtures for preparing specimens for both Gross and Net EWV (See **FIGURE No. 11**)

(e) Scale with a minimum 0.1 gram resolution and Certification of Calibration within 6 months prior to conducting EWV measurements.

(f) Beaker of sufficient volume to contain displaced water

3.2 Initial Preparation of ALL Rod Guide Specimens:

(a) Using the engine lathe, prepare both ends of each rod guide specimens for both Gross and Net EWV as shown in **FIGURE No. 9(B)**, maintaining a maximum Total Indicator Run-out (TIR) of 0.003 inches between opposite ends.

(b) Drill a 0.125 inch diameter hole through the unturned end of each rod guide specimen as shown in **FIGURE No. 9(B)**.

3.3 Measurement of Displaced Volume:

(a) If any holes or voids are present in the rod specimens, refer to **SECTION 2.4** before preceding.

(b) Fill the displacement apparatus with approximately 70°F water until the overflow tube starts to drain. Allow the excess water to drain until the overflow tube stops dripping.

(c) Completely dry the beaker. Then measure and record the weight, in grams, of the empty beaker.

(d) With the turned-end of the specimen down and a stainless steel wire inserted through the hole drilled in the end of the rod guide specimen, slowly lower the specimen into the displacement apparatus, catching the run-off in the beaker. The specimen shall be completely submerged when the overflow tube stops dripping. This shall be accomplished by suspending the specimen at the same depth utilizing the wire and a stop on the top of the displacement apparatus. Allow the excess water to drain until the overflow tube stops dripping.

(e) Measure and record the combined weight, in grams, of the displaced water and beaker.

(f) Remove the rod guide specimen from the displacement apparatus and completely dry the specimen.

(g) Repeat **SECTION 3.3(a)** through **SECTION 3.3(f)** until a total of five (5) measurements have been recorded for each rod guide specimen.

(h) Average the five (5) recorded measurements of the empty beaker. Also average the five (5) recorded measurements of the combined displaced water and beaker.

(i) Subtract the average weight of the empty beaker from the average weight of the combined displaced water and beaker to obtain the average weight of the displaced water by each specimen.

(j) For each specimen, convert the average weight of the displaced water to cubic centimeters (cc's) by dividing by the density of water at 70° F of 1 gm/cc.

3.4 Secondary Preparation of Rod Guide Specimens for Gross EWV:

NOTE: **SECTION 3.3** must be completed before proceeding.

(a) Install the Gross EWV fixture (see **FIGURE No. 11**) with the OD corresponding to the tubing and coupling combination utilized in the engine lathe. Maintain a maximum TIR of 0.001 inch along the OD of the fixture.

(b) Place the turned (small) end of the rod guide specimen into the fixture and tighten the retention set screws to secure the specimen to the fixture.

(c) Remove the material from the rod guide in incremental cuts down to the OD of the fixture. Remove the rod guide specimen from the fixture.

(d) Repeat **SECTION 3.4 (b)** and **(c)** for each Gross EWV rod guide specimen.

(e) Perform **SECTION 3.3** for the Gross EWV rod guide specimens.

(f) Go to **SECTION 3.6**.

3.5 Secondary Preparation of Rod Guide Specimens for Net EWV:

NOTE: SECTION 3.3 must be completed before proceeding.

(a) Install the Net EWV fixture (see **FIGURE No. 11)** with the OD corresponding to the tubing and coupling utilized in the engine lathe. Maintain a maximum TIR of 0.001 inch along the OD of the fixture.

(b) Place the turned (small) end of the rod guide specimen into the fixture.

(c) Rotate the rod guide specimen until the point equi-distant between two adjacent fins, point "A_1", lies on a line passing through the center of the rod guide, point "B", and the center of the fixture, point "C", as shown in **FIGURE No. 13(A)**. Tighten the retention set screws to secure the specimen to the fixture.

(d) Remove the material from the rod guide in incremental cuts down to the OD of the fixture.

(e) Loosen the retention set screws.

(f) Repeat **SECTION 3.5 (c)** through **(e)** for each point, "A_2, A_3,.....A_i" on the rod guide specimen as shown in **FIGURE No. 13(B) and (C)**.

(g) Remove the specimen from the fixture.

(h) Repeat **SECTION 3.5 (b)** through **(f)** for each Net EWV rod guide specimen.

(i) Perform **SECTION 3.3** for the Net EWV rod guide specimens.

(j) Go to **SECTION 3.6**.

3.6 Final Gross and Net EWV

(a) Subtract the displaced volume in cc's of each machined Gross and Net EWV specimens from their respective initial displaced volume in cc's to determine the corresponding Gross or Net EWV for each specimen.

(b) To determine the Final Gross or Net EWV for each rod guide design, average the corresponding Gross or Net EWV determined in **SECTION 3.6(a)** of all respective specimens measured.

(c) The Gross or Net EWV may be converted to cubic inches by multiplying the volume determined in **SECTION 3.6(b)** by 0.061 in^3/cc.

3.7 The Gross or Net EWV shall be reported in either cc or in^3, with the following information provided: Nominal Tubing Size, Sucker Rod Size, Coupling Design, Gross or Net EWV, and method of determination.

Example: Rod Guide XYZ --- 2-1/2" x 7/8" Full Size -- Gross EWV = 10 in^3 by Measurement Method, in accordance with this procedure.

SECTION 4: Calculation Method

4.1 The 3-D model of the rod guide design must truly represent either the rod guide itself or the mold from which the guide was produced. Refer to **SECTION 2** for additional requirements.

4.2 Utilizing the software capabilities, determine the initial volume of the rod guide design. See **FIGURE No. 14(A)**.

4.3 Gross EWV

(a) Pass a cutting cylinder through the rod guide, parallel to the axis of the guide. The cylinder shall be concentric with the sucker rod and its diameter shall equal the appropriate outside diameter of the corresponding coupling utilized, full or slim hole. See **FIGURE No. 14(B).**

(b) Utilizing the software capabilities, determine the volume of the rod guide remaining inside the cutting cylinder.

(c) To determine the Gross EWV, subtract the remaining volume from the initial volume determined in **SECTION 4.2**.

(d) Go to **SECTION 4.5**

4.4 Net EWV

(a) Referring to **FIGURE No. 15(A)**, determine the location of point "A_1" which is equi-distant between two adjacent fins. Draw a line connecting this point, through the center of the guide, point "B", and to point "C", located at a distance "E" from point "B" corresponding to the tubing and coupling combination utilized. See **TABLE No. 1**.

(b) Pass a cutting cylinder through the rod guide, parallel to the axis of the guide. The center of the cylinder shall be located at point "C" and its diameter shall equal the appropriate inside diameter of API Specification 5CT External Upset Tubing.

(c) Repeat **SECTION 4.4(a) and (b)** for each point, "A_2, A_3,.....A_i" on the rod guide as shown in **FIGURE No. 15(B) and (C)**.

(d) Utilizing the software capabilities, determine the volume of rod guide remaining inside all of the cutting cylinders.

(e) To determine the Net EWV, subtract the remaining volume from the initial volume determined in **SECTION 4.2**

(f) Go to **SECTION 4.5.**

4.5 The Gross or Net EWV shall be reported in either cc or in^3, with the following information provided: Nominal Tubing Size, Sucker Rod Size, Coupling Design, Gross or Net EWV, and method of determination.

Example: Rod Guide XYZ --- 2-1/2" x 7/8" Full Size -- Gross EWV = 10 in^3 by Calculation Method, in accordance with this procedure..

Conclusion

The reader should be aware that variations in EWV determined for the same rod guide design can exist using the methods described in this paper. Using the measurement method, this variation is due to differences in the specimens, fixtures, materials and technicians. But with multiple specimens and multiple measurements of each, the effects of these differences can be minimized. With the calculation method, the variation can be attributed to differences in the 3-D model and calculation accuracy of the software. The calculation method can have an additional drawback that results from variances between the actual molded guide dimensions and the 3-D model. The calculation method can be used but its limitations should be recognized and steps taken to minimize their effects.

Even though Net EWV is a mathematical representation assuming uniform wear between adjacent fins, it closely resembles wear patterns observed in the field. Net EWV is more difficult to obtain than Gross EWV but it is still a reasonable approximation of field wear patterns.

Both methods provide relevant data to the industry that can be used to compare and evaluate rod guides. Even though EWV is a major index, others of equal importance are material-wear-rate and hydraulic drag. Variables which affect these indices are pumping speeds, hole deviation, temperature, sand, chemicals, and condition of the tubing.

The acceptance of a standard such as this by the oil field industry would provide end-users and manufacturers the basis to systematically compare rod guide designs currently on the market and to benchmark future designs.

Acknowledgments

The author wishes to thank Larry Angelo and Milton Hoff of Huber Flow Control for many hours of constructive technical and editorial review, and Sharon Allen, also of Huber Flow Control, for patience through numerous re-writes.

Table 1

Nominal Tubing OD	Tubing ID TID	Nominal Sucker Rod Size	Coupling Style	Coupling OD COD	Net EWV E
2"	1.995	5/8"	Full Size	1.500	0.248
		3/4"	Slim Hole	1.500	0.248
			Full Size	1.625	0.185
		7/8"	Slim Hole	1.625	0.185
2-1/2"	2.441	3/4"	Full Size	1.625	0.408
		7/8"	Full Size	1.813	0.314
		1"	Slim Hole	2.000	0.221
3"	2.992	3/4"	Full Size	1.625	0.684
		7/8"	Full Size	1.813	0.590
		1"	Slim Hole	2.000	0.496
			Full Size	2.188	0.402

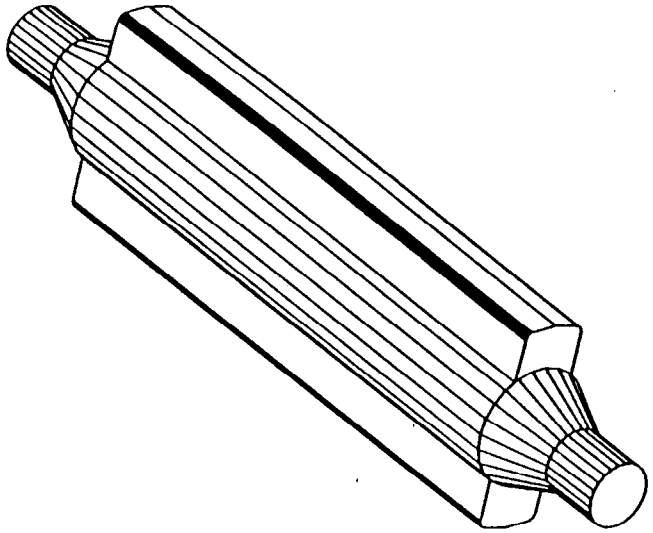


Figure 1

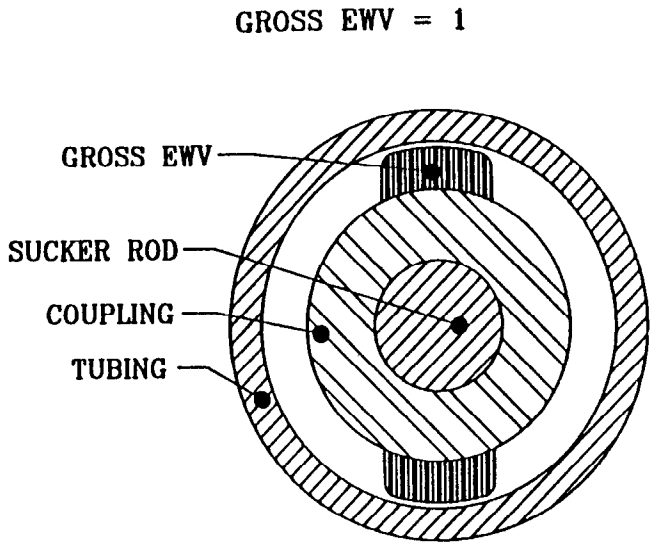


Figure 2

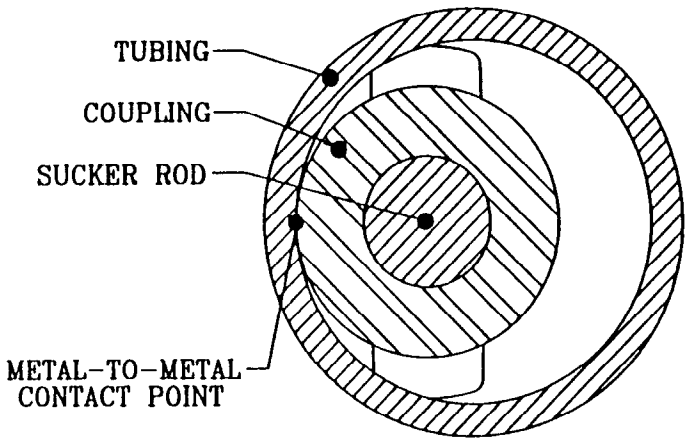


Figure 3

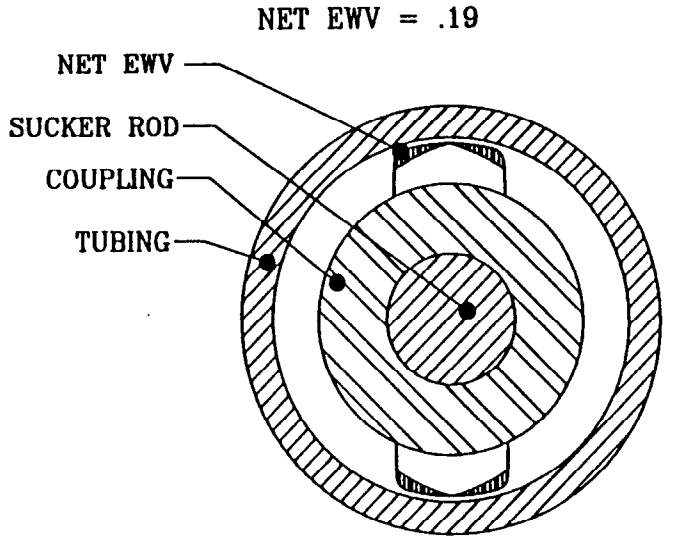


Figure 4

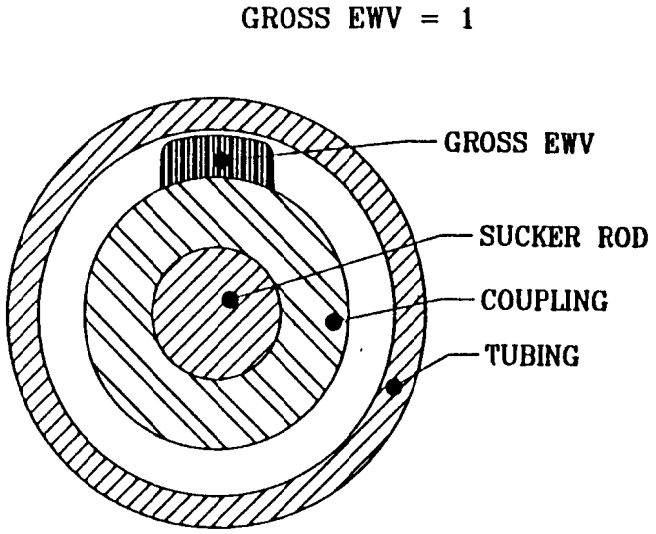


Figure 5a

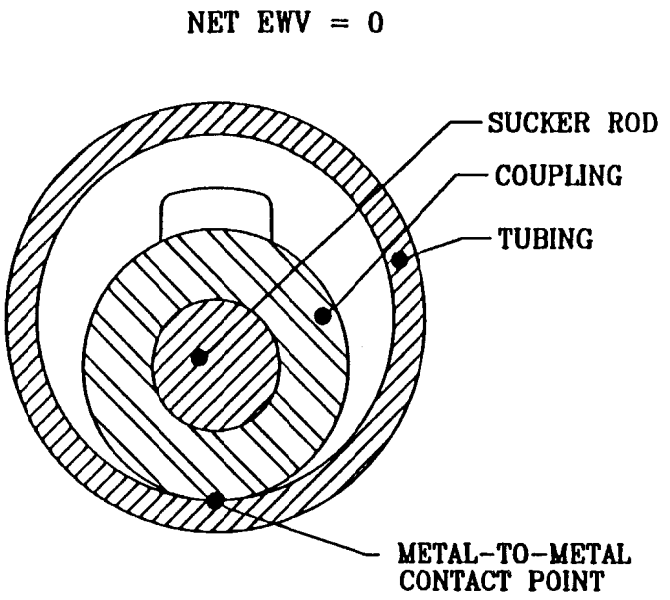


Figure 5b

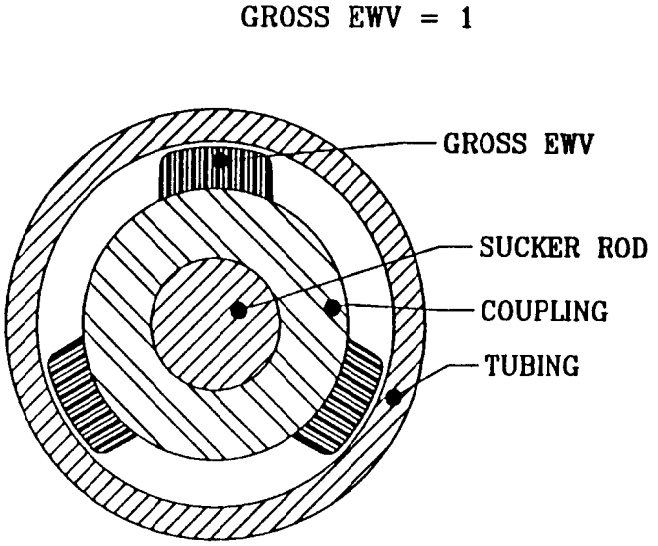


Figure 6a

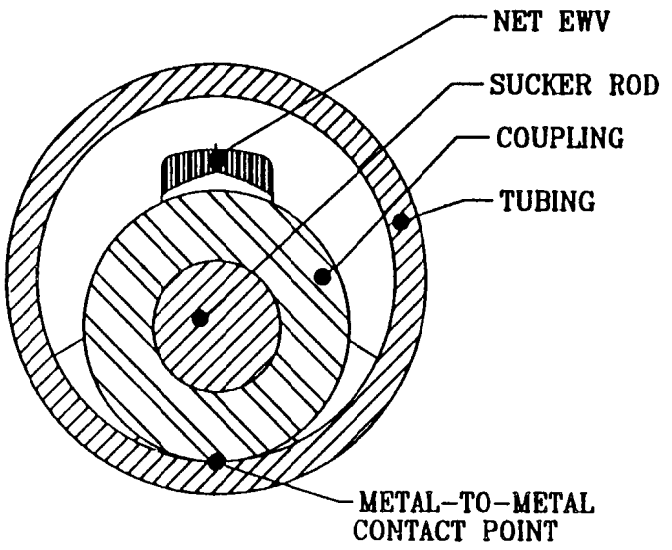


Figure 6b

GROSS EWV = 1

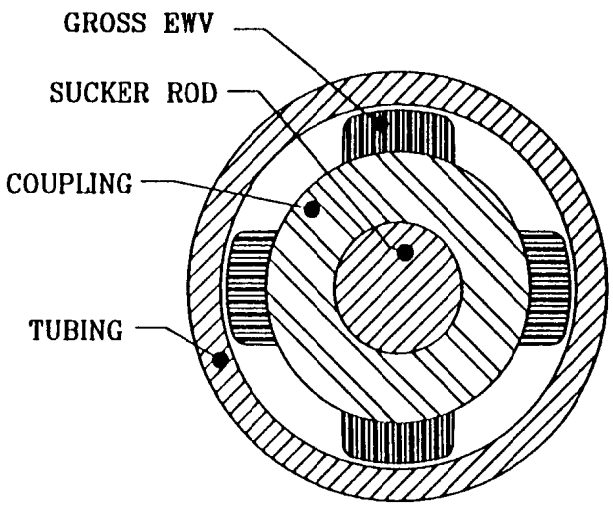


Figure 7a

NET EWV = .85

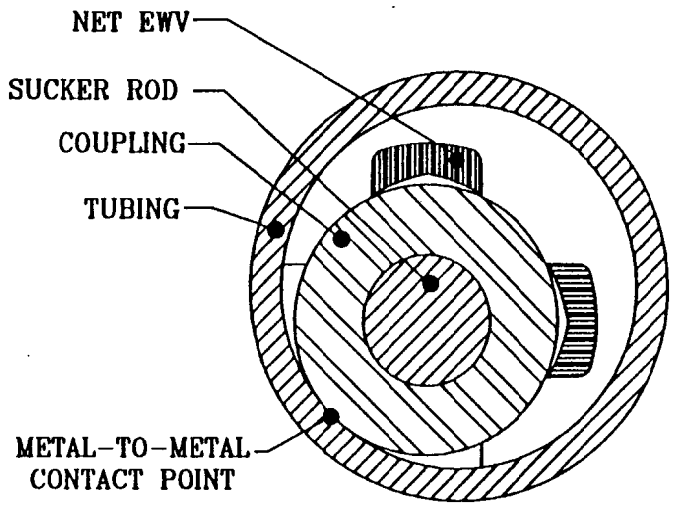


Figure 7b

GROSS EWV = 1

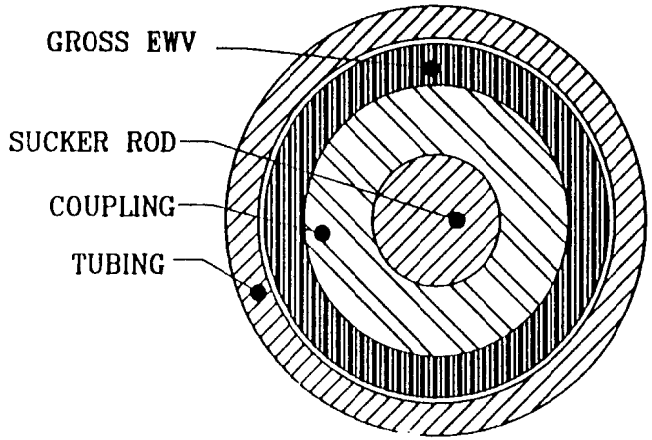


Figure 8a

NET EWV = 1

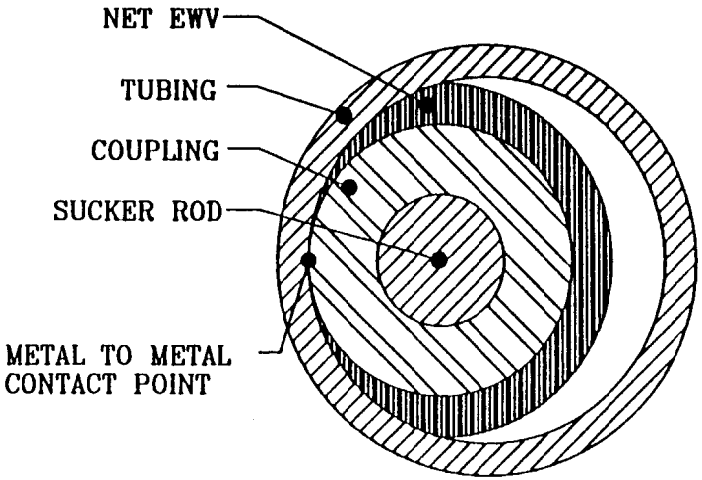
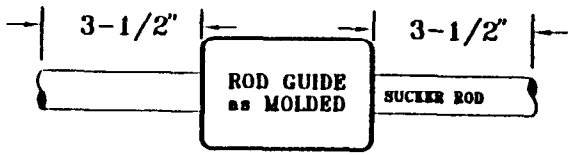
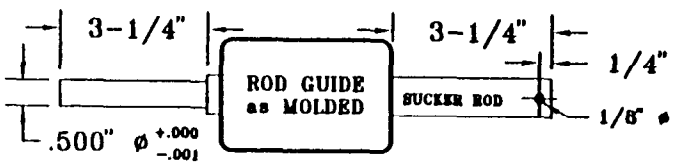


Figure 8b





Note: Break All Sharp Machined Edges

Figure 9 - Rod Guide Specimen

where:

H ≥ Length of Rod Guide Specimen + 3-1/2"

ID ≥ OD of as Molded Rod Guide Specimen

and

ID ≤ 3-1/2 inches

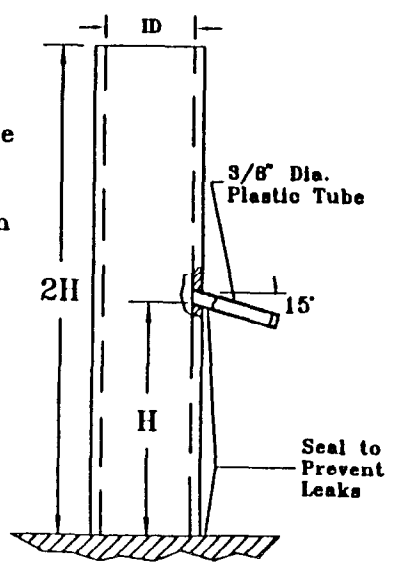


Figure 10 - Displacement Apparatus

where:

TID = Inside Dia. of API Tubing per API Specification 5CT

COD = Outside Dia. of API Coupling or Rod Box per API Spec. 11B

For Gross EWV:

OD = COD

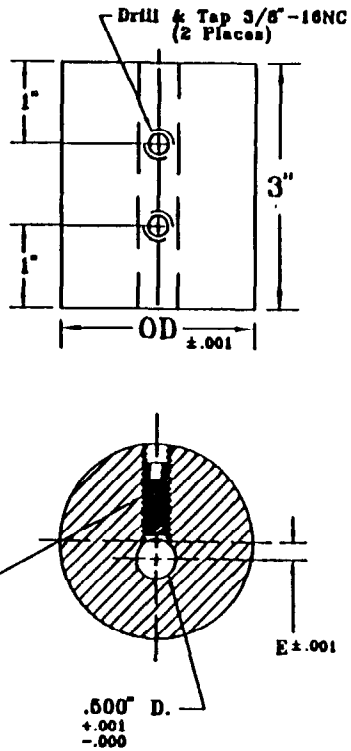
E = 0.0

For Net EWV:

OD = TID

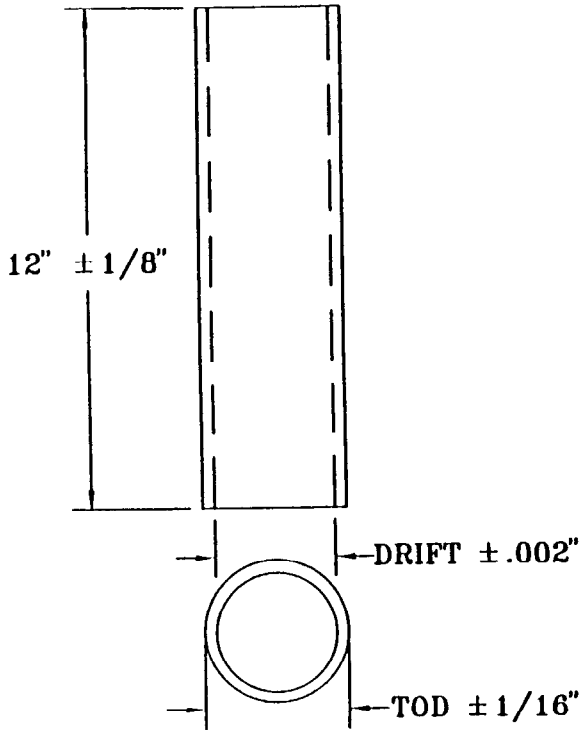
$E = \frac{TID - COD}{2}$

3/8"-16NC Socket Head Set Screw x 1/2" Long



Nominal Tubing OD	Inside Diameter TID	Nominal Sucker Rod Size	Coupling Style	Coupling OD COD	Gross EWV E	Net EWV E
2"	1.995	5/8"	Full Size	1.500	0	0.248
		3/4"	Slim Hole	1.500	0	0.248
			Full Size	1.625	0	0.185
		7/8"	Slim Hole	1.625	0	0.185
2-1/2"	2.441	3/4"	Full Size	1.625	0	0.408
		7/8"	Full Size	1.813	0	0.314
		1"	Slim Hole	2.000	0	0.221
3"	2.992	3/4"	Full Size	1.625	0	0.684
		7/8"	Full Size	1.813	0	0.590
		1"	Slim Hole	2.000	0	0.496
			Full Size	2.188	0	0.402

Figure 11 - Preparation Fixtures



Nominal Tubing OD	Actual Tubing OD TOD	Tubing Drift Dia. DRIFT
2"	2-3/8"	1.901
2-1/2"	2-7/8"	2.347
3"	3-1/2"	2.867

Figure 12 - Ring Gauge

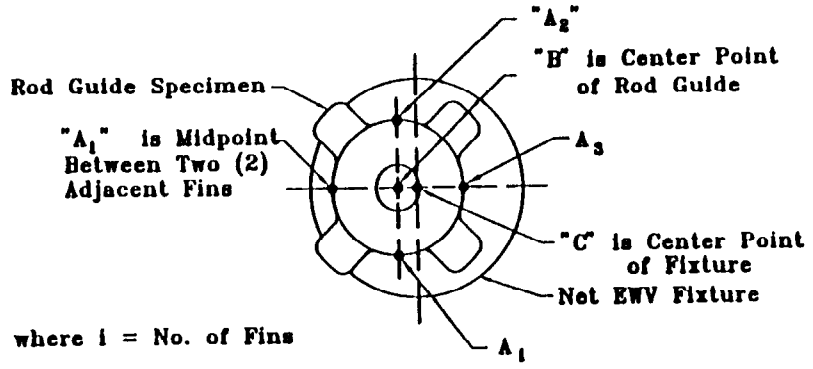


Figure No. 13(A) for A_1

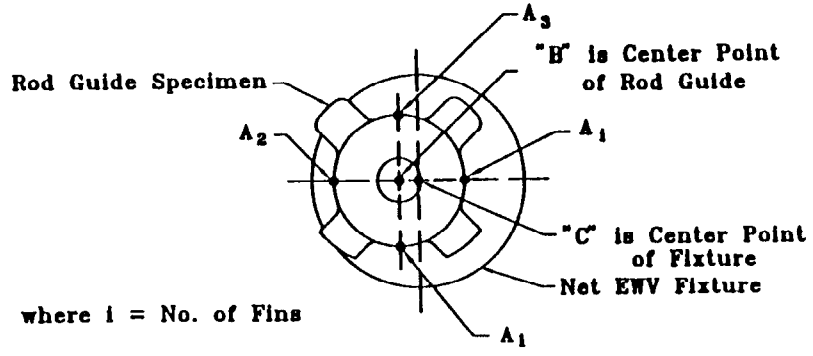


Figure No. 13(B) for A_2

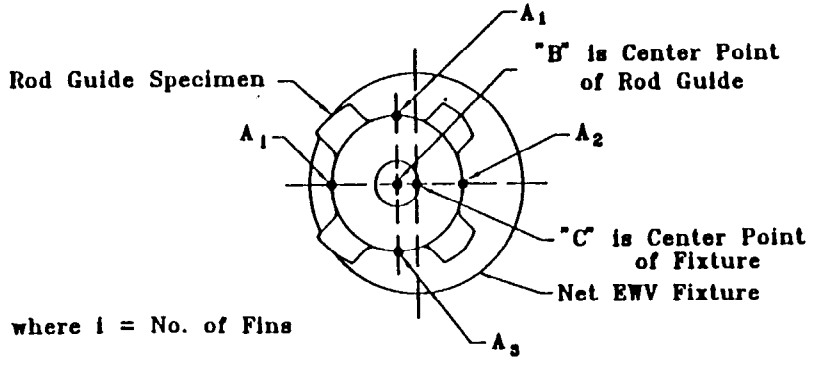
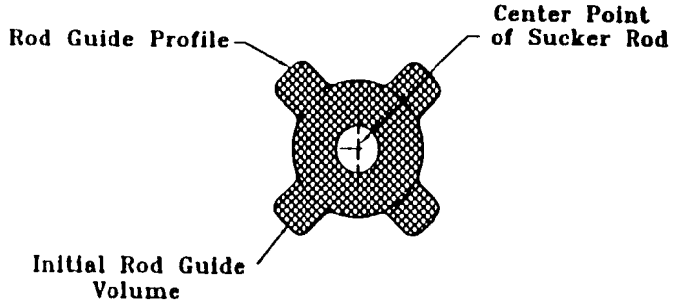


Figure 13 - Net EWV Specimen Orientation



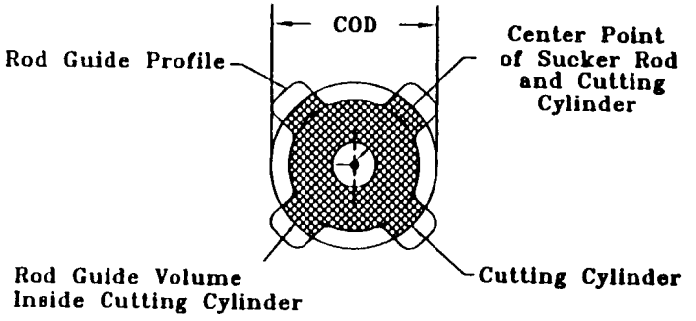
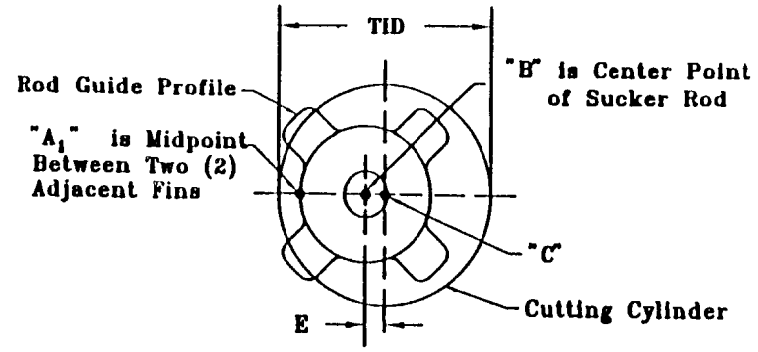
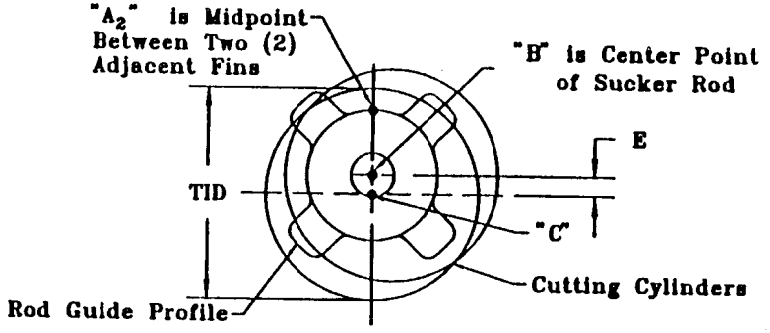


Figure 14 - Gross EWV–Calc. Method





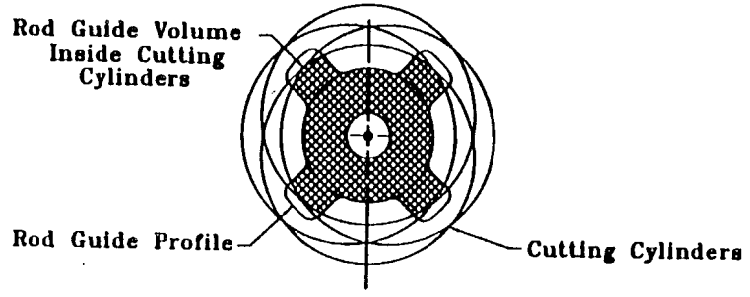


Figure 15 - Net EWV—Calc. Method