Comparing the New API Method of Calculating Sucker Rod Pumping Systems with the Older Conventional Method

By FRED D. GRIFFIN

Lufkin Foundry & Machine Company

SCOPE OF API-RP-11L

In any sucker rod pumping system, polished rod loads and, consequently, counterbalance and peak torque are complex functions of many well variables. Some of these are: (1) polished rod stroke, (2) pumping speed, (3) physical characteristics of rod string, (4) fluid column load, (5) polished rod acceleration pattern, (6) mechanical friction, (7) compressibility, (8) pump submergence, and (9) dynamics of sucker rod string.

Neither conventional calculations nor API-RP-11L consider items (6) or (7) since the magnitude of these values is nearly always unknown. Further, the conventional method usually does not take into consideration pump submergence although this is not always the case.

The API calculation method does consider the pump submergence (when it is known) and also one other very important variable that the conventional method does not consider, namely, rod dynamics. This consideration is the primary difference between the new API method and the conventional method of calculation.

The sucker rod string dynamics take into consideration: (1) viscous damping, (2) unit geometry, (3) spring constant of rods and tubing, (4) ratio of pumping speed to the natural frequency of the rod string, (5) ratio of rod stretch to the polished rod stroke, (6) variation of angular velocity of the cranks, (7) motor slippage, if electrically driven, and (8) system inertia.

In the API method some consideration is given to all these dynamic factors, except unit geometry and system inertia. The unit geometry for API-RP-11L is assumed to be of the conventional type; i.e., the equalizer bearing is located directly over the gear reducer crank shaft. Thus, the conventional crank-balanced units and air-balanced units both would fall into this category.

SIGNIFICANCE OF NONDIMENSIONAL PARAMETERS

Although this paper does not pretend to go into the highly technical aspects of API-RP-11L, it is important to consider briefly two independent variables that appear throughout API-RP-11L. These same two variables appear as the abscissa in Figs. 1 through 6 of this paper:

1. N/N_0', ratio of pumping speed to the natural frequency of the combination rod string
2. F_0/Sk_r, ratio of rod stretch to polished rod stroke

These two variables, or parameters, are the two most important variables in well load behavior.

The value of N_0', the natural frequency of the combination rod string, will usually be of the magnitude of 30 vibrations per minute or greater. Seldom will the pumping speed exceed 20 strokes per minute; therefore, the value of N/N_0' will vary between 0 and 0.6. Since the pumping speed will never exceed the natural frequency of vibration of the rod string, the higher harmonics ($2N_0'$, $3N_0'$, $3N_0'$, $4N_0'$, etc.) will never be involved. The lower order harmonics (1/2 N_0', 1/3 N_0', 1/4 N_0', etc.) will be in the operating range.

It is convenient to think of N/N_0' as "pumping speed" even though it is, in reality, dimensionless. Assume, for example, that a tapered rod string with a particular size pump has a natural frequency of 40 vibrations per minute. Then, saying that $N/N_0' = .25$, is merely saying that the pumping speed is 10 SPM and the rod string is operating at a 4th order frequency; i.e., $N/N_0' = .25 = N/40$ or $N = 10$ SPM.

Similarly, the dimensionless parameter, F_0/Sk_r, represents rod stretch. The "actual" rod stretch induced by the fluid load F_0 is F_0/k_r, where k_r is the spring constant of the rod string. Thus, $(F_0/k_r)/S$ is the rod stretch expressed as

COMPARISON OF PREDICTED AND MEASURED LOADS FOR 77 WELLS

									PUMP DISPLACEMENT		PEAK POLISHED ROD LOAD			MINIMUM POLISHED ROD LOAD			PEAK TORQUE (100% MECHANICAL EFF.)			
REPORT NO.	TYPE UNIT *	PUMP DEPTH	STROKE	SPM	API ROD COMBINATION	PLUNGER DIA.	N/N_0'	F_o/S_{kr}	API-RP-11L METHOD	CONVENTIONAL METHOD	API-RP-11L METHOD	CONVENTIONAL METHOD	MEASURED	API-RP-11L METHOD	CONVENTIONAL METHOD	MEASURED	API-RP-11L METHOD	CONVENTIONAL METHOD	MEASURED (C'BAL. CORRECTED)	MEASURED (C'BAL. AS MEASURED)
175	M	7,554	99.7	14.5	76	1¼	.419	.328	264	268	21,478	18,361	16,920	8,104	6,173	5,612	—	—	163,000	214,000
176	M	8,561	100	12	86	1½	.365	.411	261	256	27,074	24,378	18,840	10,962	10,409	11,220	—	—	103,000	108,000
178	C	3,64	74	16	66	2	.207	.176	476	485	11,864	10,263	11,550	1,201	3,123	2,100	204,886	139,230	178,000	198,300
180	C	3,595	44	22	76	2½	.295	.149	688	460	11,977	15,830	11,850	2,884	3,939	2,550	125,001	136,735	108,800	115,300
185	C	5,644	100	14.5	86	1¾	.289	.140	514	470	20,011	20,103	21,600	5,312	6,913	6,300	400,687	342,940	418,000	464,000
183	M	2,350	86	15	66	2	.181	.122	541	554	11,631	9,088	10,950	1,727	2,361	1,969	—	—	147,000	195,000
191	C	5,595	76	17	86	1¾	.335	.124	455	409	18,455	20,094	19,130	5,364	6,685	6,450	269,140	274,864	268,000	271,000
192	M	7,850	119.5	7.5	76	1½	.224	.229	184	191	20,053	19,367	16,500	10,047	10,508	10,280	—	—	225,000	229,000
195	C	5,200	12	9.3	86	2	.170	.182	460	455	20,232	18,841	20,100	6,290	8,245	8,090	465,713	339,072	491,000	536,000
207	M	2,681	85.5	16	76	2¾	.160	.163	1068	1055	15,355	12,392	12,330	475	2256	299	—	—	177,000	212,000
213	M	2,642	144	11	87	2¾	.110	.200	1,140	1,347	12,497	13,533	15,710	4,584	3,454	452	—	—	305,000	413,000
216	M	7,925	145.6	12.8	86	1½	.361	.242	489	479	28,475	23896	23,000	7,388	6,550	7,380	—	—	391,000	523,000
220	M	8,750	100	13	86	1½	.404	.429	310	289	28,148	25,315	24,500	10,921	9,726	8,630	—	—	363,000	377,000
221	C	4,925	100	12	76	2	.222	.262	470	454	18,617	16658	15870	3,972	6,131	4,680	397,228	210520	328,000	360,000
240	M	4,748	86	11	86	2	.196	.268	362	341	16,842	15,039	15,740	4,667	5,880	3,290	—	—	208,000	227,000
245	C	4,300	74.7	15	76	2	.242	.267	400	429	16,689	14,825	15,890	5,378	5,073	3,480	270,368	311,805	222,200	224,400
256	C	2,790	63	13	66	2¼	.148	.188	411	403	11,130	9,530	9,980	2,180	3,292	1,750	157,000	106,046	135,700	173,000
260	C	4,650	86	14	76	2	.246	.271	469	459	17,905	16,032	17,790	3,346	5,487	3,170	331,081	237,240	347,000	427,000
270	M	5,227	120	11	76	2	.216	.121	591	532	16,357	16,897	16,490	5,256	5,684	3,490	—	—	260,000	279,000
272	M	6,690	144	12	86	2	.282	.245	677	719	27,773	24,557	26,020	6,433	6,751	6,170	—	—	576,000	718,000
274	C	5,153	64	16	66	1½	.337	.242	238	241	14,296	13,345	10,800	4,362	5,389	4,140	165,056	135,252	126,000	190,000
285	M	3,091	86	14.7	66	2¼	.186	.116	686	663	11,710	10,619	12,430	1,878	2542	150	—	—	197400	212,800
286	M	9,126	120	9.5	86	1½	.308	.339	220	243	28,026	25,420	27,260	12,328	12,429	13,340	—	—	427,000	507,000
291	C	5,020	64	12	76	1¾	.228	.157	261	205	13,197	14,581	15,280	5,592	6,839	6,100	140,155	131,614	163,000	180,000
295	C	9550	173	6.7	86	1¼	.230	.176	198	192	25,826	24,399	23,200	13,425	14,828	15,820	641,163	416,295	519,000	565,000
296	M	7,500	168	10.4	86	1¾	.275	.250	615	549	28,822	24,311	29,100	7,172	5,141	8,930	—	—	660,000	1,083,000
297	M	8,000	168	9.6	86	1¾	.271	.284	461	463	29,104	25,575	21,500	8,750	9,582	13,570	—	—	423,000	637,000
300	C	2,360	54	16	66	2¼	.154	.157	423	443	9,814	8,235	10,562	1,471	2,611	1,625	120,340	87,686	141,300	165,700
302	C	5,372	74	18	76	1¾	.366	.338	439	417	19,581	17,664	13,734	3,883	5,612	4,140	284,980	235,014	177,400	270,500
303	C	4,300	74	17	76	2	.274	.269	440	496	17,287	15,338	16,981	2,616	4,561	4,675	288,795	210,132	240,400	278,000
319	C	2,396	54	13	66	2⅛	.127	.120	318	331	8478	7,662	9,800	2,400	2,913	1,013	89,002	68,846	129,101	149,122
322	C	2,400	52	15	76	2¼	.134	.149	390	403	10,545	8,895	10,240	2,427	3,203	1,916	116,274	79,688	109,900	114,100
324	C	4,325	74	16.5	76	2	.267	.225	468	503	16,695	15290	16,250	3,207	4,725	4,330	271,951	205,998	232,500	256,000
334	M	4,350	74	11.5	66	1½	.204	.147	209	198	11,729	10,597	11,375	4,640	5,217	3,006	—	—	148,900	203,900
347	C	7,129	86	9	76	1½	.244	.367	147	145	19,276	18,177	20,360	8,775	9,632	8,660	205,860	192,240	275,948	447,000
351	C	2,358	44	19	66	2¼	.183	.192	434	467	9,827	8,340	10,179	1,130	2,497	946	105,789	67,183	104,500	106,000
352	C	2,383	44	20.5	66	2¼	.199	.196	474	452	10,192	8,572	10,296	991	2,379	1,287	112,065	71,208	95,000	100,000
353	C	4,326	74	18.3	76	2⅛	.296	.222	625	625	16,697	16,694	19,890	2,782	4,226	819	292,350	243,126	358,000	368,000
354	C	3,821	74	20	76	2	.287	.153	675	616	15,652	14,462	19,422	1,512	3,221	234	281,134	219,180	364,000	369,000
355	C	4,675	100	13	76	1½	.231	.136	329	320	15,396	13,118	19,588	4,027	5,374	3,320	323,162	201,344	427,000	483,000
365	C	2,750	100	16.2	66	2⅛	.182	.103	811	803	12,403	9,300	12,948	830	2,238	1,162	300,709	199,212	274,000	336,000
370	M	4,126	120	13.7	76	2¼	.211	.191	877	847	19,775	15,456	10,790	1,660	3,304	0	—	—	254200	404,300
384	C	3,775	100	17	76	2⅛	.240	.172	817	819	17,941	14,978	17,635	725	3,277	1,088	469,973	304,200	430,508	464,000
386	C	3,775	100	14.5	76	2⅛	.204	.172	702	680	16,596	14,185	17,080	1,801	4,070	2,691	407,575	257,400	375,000	412,000
402	M	4,200	120	14	86	2	.148	.139	671	733	20,584	16,328	17,175	3,177	4,949	1,374	—	—	442,000	598,000
403	C	3,414	42	16.5	77	1½	.229	.262	158	155	11,928	10,453	9,490	4,342	5,330	3,908	91,344	70,048	66,100	95,800
404	M	5,915	168	11	86	2	.228	.124	840	766	23,745	21,671	23,520	5,378	6,059	360	—	—	751,000	804,000
413	M	5,474	168	11	86	2½	.215	.208	1,129	1,166	20,141	25,065	27,144	4,106	5,832	2,340	—	—	770,000	785,000
414	C	2,967	74	12.1	76	2¼	.134	.160	446	456	12,827	10,920	12,513	2,557	4,028	2,457	188,303	134,394	209,100	226,900
419	C	4,600	64	14	87	1½	.249	.154	229	219	16,914	15,231	[illegible]	5,920	7,652	6,201	207,886	128,826	85,800	115,500
428	M	9,250	168	10	86	1¼	.332	.105	309	316	26,512	24,201	26,208	10,632	10,136	9,828	—	—	675,000	895,000
434	C	3,555	100	13	76	2¼	.172	.170	638	670	16,371	13,673	16,300	2,450	4,249	2,106	379,410	245,024	369,700	412,100
435	C	9,425	120	10.3	86	1¼	.349	.269	200	205	26,650	25,406	28,314	12,250	13,252	12,636	445,000	382,851	538,500	584,100
436	C	9,584	168	8	86	1¼	.275	.180	233	231	26,300	25,324	26,714	12,767	14,042	15,444	694,072	490,767	737,000	968,000
437	C	8,975	128	6.5	86	1¼	.210	.250	129	124	23,667	22,327	25,272	13,066	14,538	13,923	390,920	260,898	442,400	479,600
440	M	8,012	120	9.5	86	1½	.271	.256	252	259	24,648	22,334	27,560	10,591	10,897	9,275	—	—	460,700	592,800
441	A	3,200	144	9	68	7⅞	.117	.098	1,126	1,035	21,795	18,247	25,000	4,678	6,069	2,535	648,261	438,408	740,800	900,700
443	C	2,414	54	18	66	2¼	.177	.138	508	514	9,852	8,627	10,624	1,620	2,465	1,500	118,280	89,349	126,900	177,600
444	M	6,400	120	11	76	2	.264	.168	443	451	23,331	21,672	19,923	5,870	7,944	5,931	—	—	275,700	371,600
453	C	2,478	74	16	76	2¼	.148	.112	624	641	12,136	9,665	11,288	1,750	2,826	1,079	199,339	133,341	134,100	191,800
454	C	1,844	42	22	76	2¾	.151	.157	691	732	10,974	8,962	7,800	700	2,107	0	108,434	75,394	70,500	90,000
455	C	2,623	64	18	65	2¼	.174	.162	582	596	10,138	8,342	12,450	864	2,170	747	156,654	115,124	162,400	193,200
463	M	5,200	86	14	76	2	.273	.339	483	433	19,491	16,993	15,550	4,246	5,207	2,870	—	—	162,000	165,200
464	M	7,309	144	9.1	86	1¾	.235	.226	416	401	25,291	22,865	23,738	9,220	9,858	6,750	—	—	460,100	478,000
472	C	6,884	100	7.6	66	1¾	.427	.229	779	644	27,600	26,567	29,100	5,871	6,364	3,660	510,583	570,572	615,500	631,066
476	C	3,824	120	9.4	87	2½	.136	.148	732	721	20,228	17,923	21,760	5,381	6,848	3,180	295,923	349,020	596,900	674,000
477	A	4,062	146	13.2	87	2¾	.202	.161	1,563	1,525	27,341	22,153	13,000	262	4,060	2,130	1,025,200	659,628	797,000	812,400
484	C	3,509	54	10	65	1½	.130	.178	113	116	7,780	7,166	7,933	3,177	3,715	3,173	73,307	50,025	61,200	94,600
485	C	3,585	54	15	65	1½	.196	.198	160	182	8,741	7,671	7,849	2,327	3,291	2,422	38,432	63,510	63,700	35,600
493	M	10,336	120	8	86	1½	.294	.380	183	167	26,492	26,212	26,700	15,219	15,413	14,940	—	—	259,100	426,300
501	C	3516	120	9	88	3¾	.129	.115	1,224	309	21,610	23,408	22,200	5,350	7,504	4,200	512,342	500,976	571,200	368,400
502	A	6,015	240	6	87	2¾	.136	.205	1,175	1,217	33,456	29,344	31,625	8,153	10,540	—	1,732,164	1,164,240	1,326,500	[illegible]
509	A	6,900	120	16.3	86	2	.335	.326	874	859	31,452	26,756	30,455	5,557	4,233	3,229	746,701	724,561	735,100	882,500
526	C	4,876	124	15	86	2¼	.258	.222	388	1,032	26,011	22,501	20,463	2,351	5,243	3,530	800,209	560,690	533,000	562,500
532	C	5,016	120	10	76	1¾	.190	.175	386	376	17,176	14,928	15,555	4,395	6,474	5,330	424,700	266,301	323,000	
536	C	3,950	64	10	66	1½	.161	.165	149	145	11,188	10,183	11,352	4,837	5,671	4,930	121,107	76,704	116,000	165,300
538	A	6,342	240	7	87	2¼	.185	.156	893	833	31,038	28,819	33,862	8,200	11,064	—	1,500,421	1,065,240	1,235,000	1,445,000

* C-CONVENTIONAL UNIT
M-UNCONVENTIONAL GEOMETRY
A-AIR BALANCED UNIT

TABLE 1

a fraction of the polished rod stroke. A sucker rod system having a value of $F_0/Sk_r = .4$ is a system that has 40 per cent of the polished rod stroke taken up in rod stretch. When operating at very low speeds, where overtravel is nil, this means that the net stroke at the plunger is 60 per cent of the polished rod stroke. Once again, it is convenient to think of F_0/Sk_r as rod stretch although it, too, is dimensionless. The value of F_0/Sk_r should not be pictured as a measure of the size of the pumping unit. For example, two units shown on Table 1 (Report No. 303 and 435) each have an F_0/Sk_r value of .269. The unit for Report No. 303 is for a 74-in. stroke unit pumping from 4300 ft, with a 2-in. pump, 7/8-3/4 rods, and requires a 320 API reducer size.

The unit for Report No. 435 is for a 120-in.-stroke unit pumping from 9425 ft with a 1-1/4 in. pump, 1-7/8 - 3/4-in. rods, and requires a 640 API gear reducer size.

It is seen that one value of the nondimensional parameter F_0/Sk_r can cover a whole series of pumping units, rod strings and plunger sizes. Thus, these two important nondimensional parameters, N/N_0' and F_0/Sk_r, allow correlation of a whole group of pumping installations without having to consider individually an infinite number of cases.

NOMENCLATURE

In comparing the formulas for calculating peak polished rod load, minimum polished rod load, and peak torque for both the conventional and the API methods, the following nomenclature will apply:

PPRL = peak polished rod load in pounds
MPRL = minimum polished rod load in pounds
PT = peak torque in inch pounds
W_{ra} = weight of the rod string in air, pounds
W_{rf} = weight of the rod string in fluid, pounds
L = pump depth in feet
S = polished rod stroke in inches
N = pumping speed in strokes per minute
A_p = full plunger area in square inches
A_r = average area of the rod string, square inches
F_0 = $.433L(A_p)$ = total weight of fluid in pounds based on full plunger area
k_r = spring constant of the rod string in pounds per inch
G = modifying factor for conventional units to correct for the deviation from simple harmonic motion, usually has a magnitude of about 1.05 for conventional crank balanced units and a value of 1 for air balanced units.
G_1 = same as G above except that it applies to the upstroke on special geometry units only, usually has a magnitude of about 0.93.
G_2 = same as G above except that it applies to the downstroke of special geometry units only, usually has a value of 1.2
F_1 = peak polished rod load less the weight of the rod string in fluid, pounds
F_2 = weight of rod string in fluid less the minimum polished rod load, pounds
T = crank torque without correction factors, inch pounds
T_a = torque adjustment constant

PEAK POLISHED ROD LOAD

The most widely used conventional method of predicting peak polished rod load is shown in two forms in equations (1), (2), and (3) below for conventional units.

For those who prefer to express fluid load as a function of net plunger area:

$$PPRL = .433L(A_p - A_r) + W_{ra} + W_{ra} \; (SN^2/70{,}500) \quad (1)$$

Another approach which gives identical results defines fluid load as a function of full plunger area:

$$PPRL = .433(A_p) + W_{rf} + W_{ra} \times (SN^2/70{,}500) \quad (2)$$

or

$$PPRL = F_0 + W_{rf} + W_{ra} \times (SN^2/70{,}500) \quad (3)$$

For units with special geometry:

$$PPRL = F_0 + W_{rf} + .6W_{ra} \times (SN^2/70{,}500) \quad (3a)$$

For air balanced units:

$$PPRL = F_0 + W_{rf} + .7\,W_{ra} \times (SN^2/70{,}500) \quad (3b)$$

By inspection it is obvious that while the conventional method of predicting peak polished rod load does consider the acceleration of the rod string, it does not take into account the harmonic effects of a vibrating rod string.

The API method for predicting peak polished rod load is as follows:

$$PPRL = W_{rf} + (F_1/Sk_r) \times Sk_r \quad (4)$$

The term F_1/Sk_r is a nondimensional parameter taken from a curve in API-RP-11L which plots F_1/Sk_r against N/N_0 for a series of values of F_0/Sk_r. These curves take into account the effect of rod string harmonics as well as the normal acceleration effects. The API method does not introduce any modifying factors to take into account units with special geometry.

MINIMUM POLISHED ROD LOAD

The conventional formula for minimum polished rod load for conventional geometry units is:

$$MPRL = W_{rf} - W_{ra} (SN^2/70{,}500) \quad (5)$$

For units with special geometry:

$$MPRL = W_{rf} - 1.4\, W_{ra} \times (SN^2/70{,}500) \quad (5a)$$

For air balanced units:

$$MPRL = W_{rf} - 1.3\, W_{ra} \times (SN^2/70{,}500) \quad (5b)$$

Here again the deceleration of the rod string is considered but the dynamic effects are not.

The API method for predicting minimum polished rod load is:

$$MPRL = W_{rf} - (F_2/Sk_r) \times Sk_r \quad (6)$$

The term F_2/SK_r is a nondimensional parameter taken from a curve in API-RP-11L which plots F_2/Sk_r against N/N_0 for a series of values of F_0/Sk_r.

These curves do consider the normal deceleration effects plus the effects of rod harmonics.

PEAK TORQUE

The conventional method of calculating peak torque for units with conventional geometry is:

$$PT = (PPRL) - (MPRL) \times S2 \times G \quad (7)$$

For units with special geometry:

$$PT = (PPRL) \times (G_1) - (MPRL) \times (G_2) \times S/2 \quad (8)$$

The API method for calculating peak torque is:

$$PT = (2T/S^2k_r) \times Sk_r \times T_a \quad (9)$$

The factor $2T/S^2k_r$ is taken from a curve in API-RP-11L which plots $2T/S^2k_r$ against N/N_0 for various values of F_0/Sk_r. T_a is a torque adjustment factor.

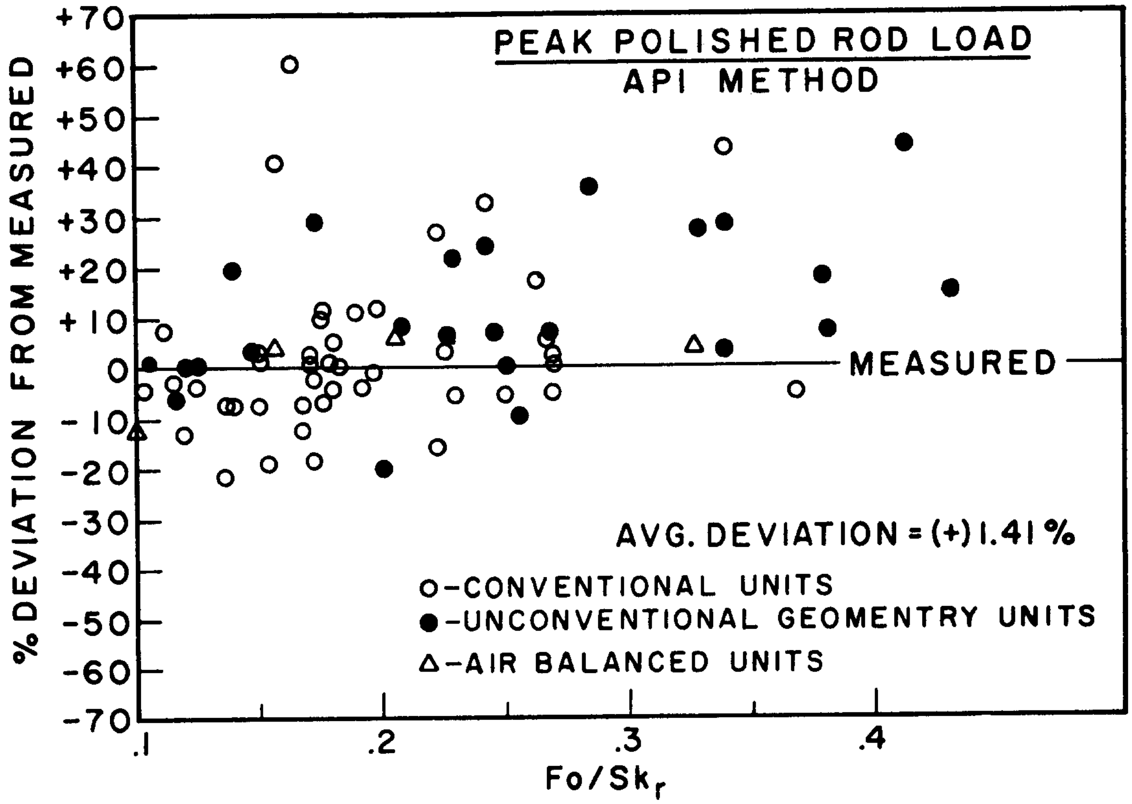
Both the conventional and the API methods of calculating peak torque assume that the peak and minimum polished rod loads occur at a crank position which results in an optimum mechanical advantage. Thus, the assumption is that the peak and minimum polished rod loads for conventional units occur at the 75° and 285° crank positions. As is commonly known, this is not always the case. When these loads do come at positions on the crank cycle other than these assumed positions, then errors of considerable magnitude may result regardless of the method of calculation used.

The assumption is also made that there is no fluid pound or gas interference. This is not the usual case, but it would be difficult to include these factors in any mathematical formulation.

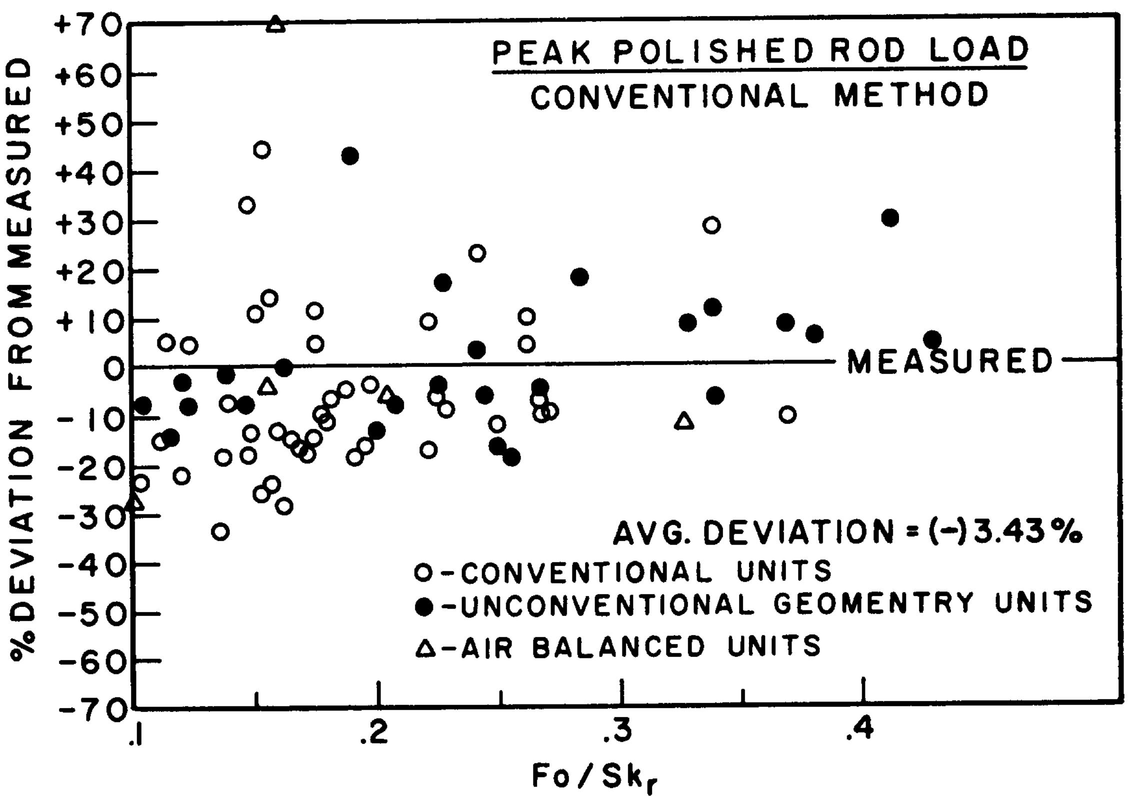
API-RP-11L does not include a peak torque prediction for units with special geometry.

Another assumption that the API method makes is that the mechanical efficiency of the pumping unit is 100 per cent. Some conventional methods of calculating peak torque make this same assumption although at least one major manufacturer uses a mechanical efficiency of 93 per cent. Values tabulated in this paper for the conventional method, however, assume 100 per cent mechanical efficiency so that they will be on a comparable basis with the API method. It could be argued at length as to just what the mechanical efficiency of a pumping unit, from the polished rod to the slow speed gear, should be; however, it definitely is not 100 per cent. An efficiency of 93 per cent seems reasonable when comparing the mechanism of a pumping unit with similar types of machinery. It is recommended that the API consider a mechanical efficiency factor in future revisions of API-RP-11L.

Still another assumption that both the API method and the conventional method make in predicting peak torque is that the pumping unit is always perfectly counterbalanced. This is a very naive assumption to say the least! Of the 77 wells listed in Table 1, the average increase in actual torque on the gear reducer over what it would have been with perfect counterbalance was 19.7 per cent. Some units were overloaded



PEAK POLISHED ROD LOAD
API METHOD
% DEVIATION FROM MEASURED
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
MEASURED
AVG. DEVIATION = (+) 1.41 %
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Sk$_r$



PEAK POLISHED ROD LOAD
CONVENTIONAL METHOD
% DEVIATION FROM MEASURED
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
MEASURED
AVG. DEVIATION = (-) 3.43 %
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Sk$_r$

FIGURE 1

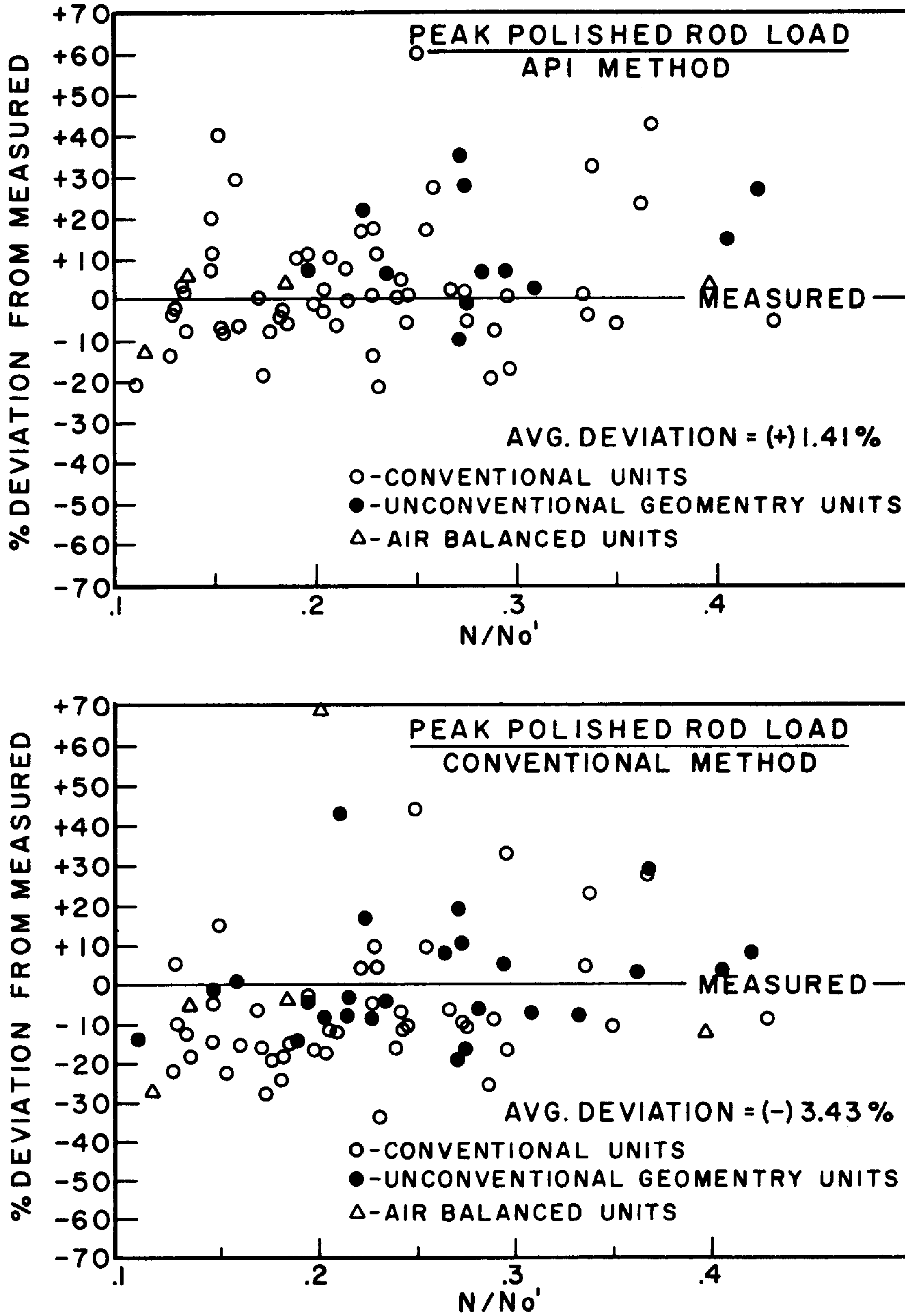

PEAK POLISHED ROD LOAD
API METHOD
AVG. DEVIATION = (+) 1.41%
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
MEASURED
% DEVIATION FROM MEASURED
N/No'
PEAK POLISHED ROD LOAD
CONVENTIONAL METHOD
AVG. DEVIATION = (−) 3.43%
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
MEASURED
% DEVIATION FROM MEASURED
N/No'

FIGURE 2

well over 50 per cent with respect to gear reducer torque due to an out-of-counterbalance condition. It is regretfully true that many operators do not fully appreciate the real importance of correct counterbalance as a most important influence on the torque imposed on a gear reducer. An out-of-counterbalance condition should always be considered, if we are to be realistic, in determining the size of the pumping unit reducer no matter which method of calculation is used. It is, therefore, recommended that a multiplying factor of 1.2 always be applied to the calculated required torque before the final selection of the pumping unit reducer is made. This recommendation will not necessarily result in a larger gear reducer than would have been selected previously, but it may do so, depending upon where the calculated torque, as modified, falls.

COMPARISON OF PREDICTED AND MEASURED LOADS FOR 77 WELLS

In comparing the API method with the conventional method of calculating peak polished rod load, minimum polished rod load, and peak torque, it is meaningful to compare both methods with measured results taken from dynamometer studies recorded over a period of several years. In these studies the peak and minimum loads are taken directly from the dynamometer cards. The counterbalance effect is calculated from the reported position and size of the counterweights. The peak torque on the gear reducer in all cases had been calculated by API-STD-11E using accurate torque factors for the polished rod positions taken at every 15 degrees of crank rotation.

An effort was made in selecting the dynamometer studies, whose results are recorded in Table 1, to cover a wide range of conditions, considering production, depth, pumping speed, and pumping unit size. Dynamometer cards with obvious well abnormalities were not considered.

Peak Polished Rod Loads

Referring to Figs. 1 and 2, it is noted that strictly from a standpoint of averages, the API method for predicting peak polished rod load is very accurate, predicting loads that average only 1.41 per cent greater than measured. The conventional method predicts peak polished rod loads that average only 3.43 per cent less than measured. While the "average" deviation for both methods is certainly accurate enough, not too much can be said for the range of predicted loads. For the API method (excluding the very extreme deviations), 95 per cent of the wells fall in a range of from −22 per cent to a +32 per cent. Similarly, the conventional method predicts loads that are measured to be −30 per cent to a +25 per cent.

It is disappointing in both methods that the range of deviation of calculated from measured is so great. It should not be so surprising, perhaps, if it is considered that so many of the variables that affect well loads are either too complex for mathematical treatment or are variables that depend upon well data that is nearly always unavailable at the time of computation.

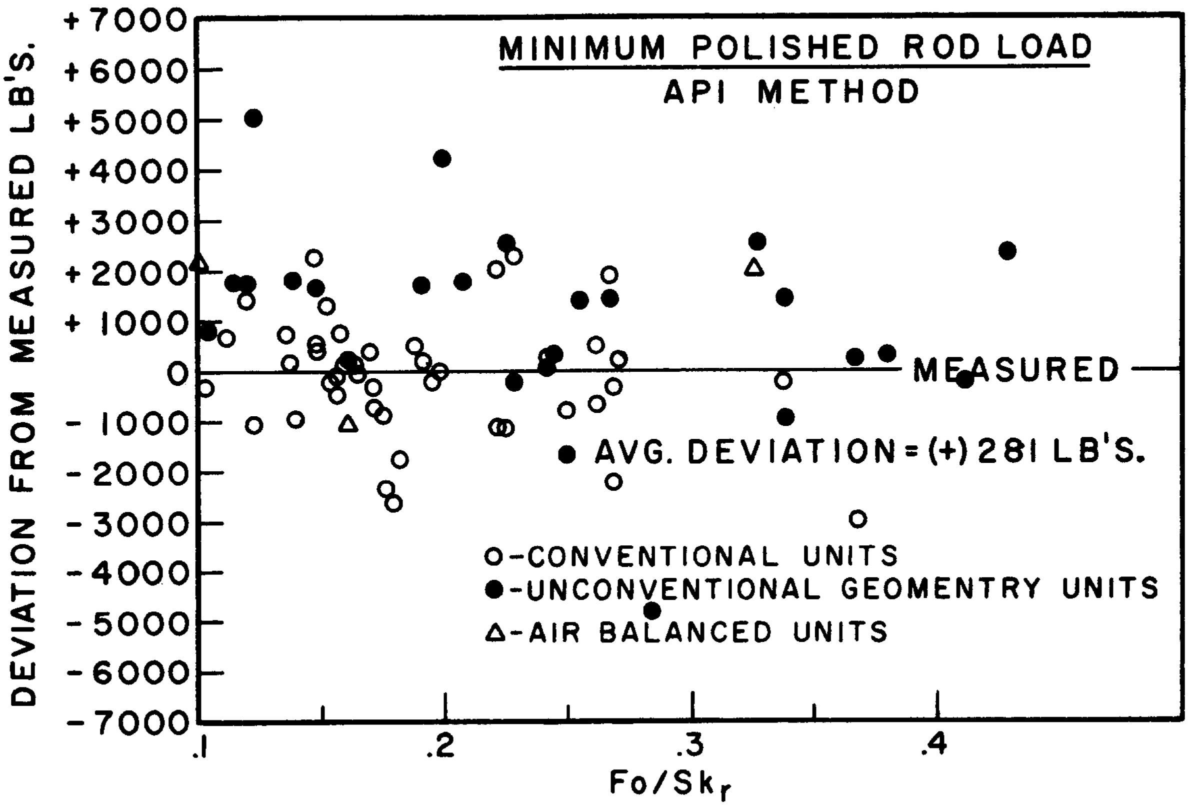
Minimum Polished Rod Loads

In the calculations for minimum polished rod loads, results show that the API method is definitely superior to the conventional method (Figs. 3 and 4). The API method made predictions that averaged only 281 pounds above measured; whereas, the conventional method predicted minimum loads that averaged 1299 pounds above measured. Once again the range of deviation in both methods was wider than would have been desired.

Peak Torque

Considering the fact that both methods, on an average basis, predict peak loads that deviate from measured only a small amount, and considering the fact that the API method was shown to be considerably more accurate with respect to minimum load, we could expect the API method to be more accurate on a torque comparison. This proves to be the case.

Referring to Figs. 5 and 6, the API method predicts torque values that average 7.26 per cent above measured. The conventional method calculates torques that are 18.82 per cent below measured results. Thus, the API method is more conservative than the older method of calculation. The wide range of deviation from measured in the torque calculations reflects, of course, the wide range of deviations in both the peak and minimum polished rod loads discussed previously.


MINIMUM POLISHED ROD LOAD
API METHOD
DEVIATION FROM MEASURED LB'S.
+7000
+6000
+5000
+4000
+3000
+2000
+1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
MEASURED
AVG. DEVIATION = (+) 281 LB'S.
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Skr

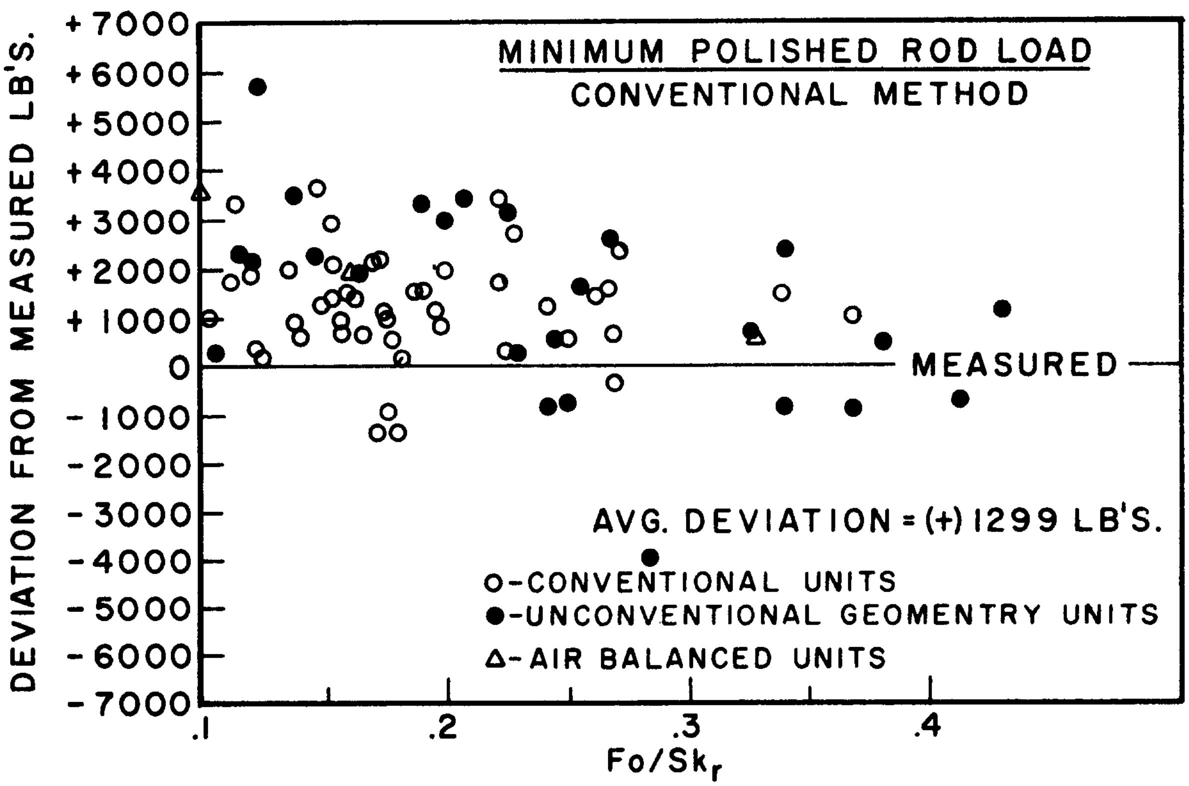

MINIMUM POLISHED ROD LOAD
CONVENTIONAL METHOD
DEVIATION FROM MEASURED LB'S.
+7000
+6000
+5000
+4000
+3000
+2000
+1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
MEASURED
AVG. DEVIATION = (+) 1299 LB'S.
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Skr

FIGURE 3

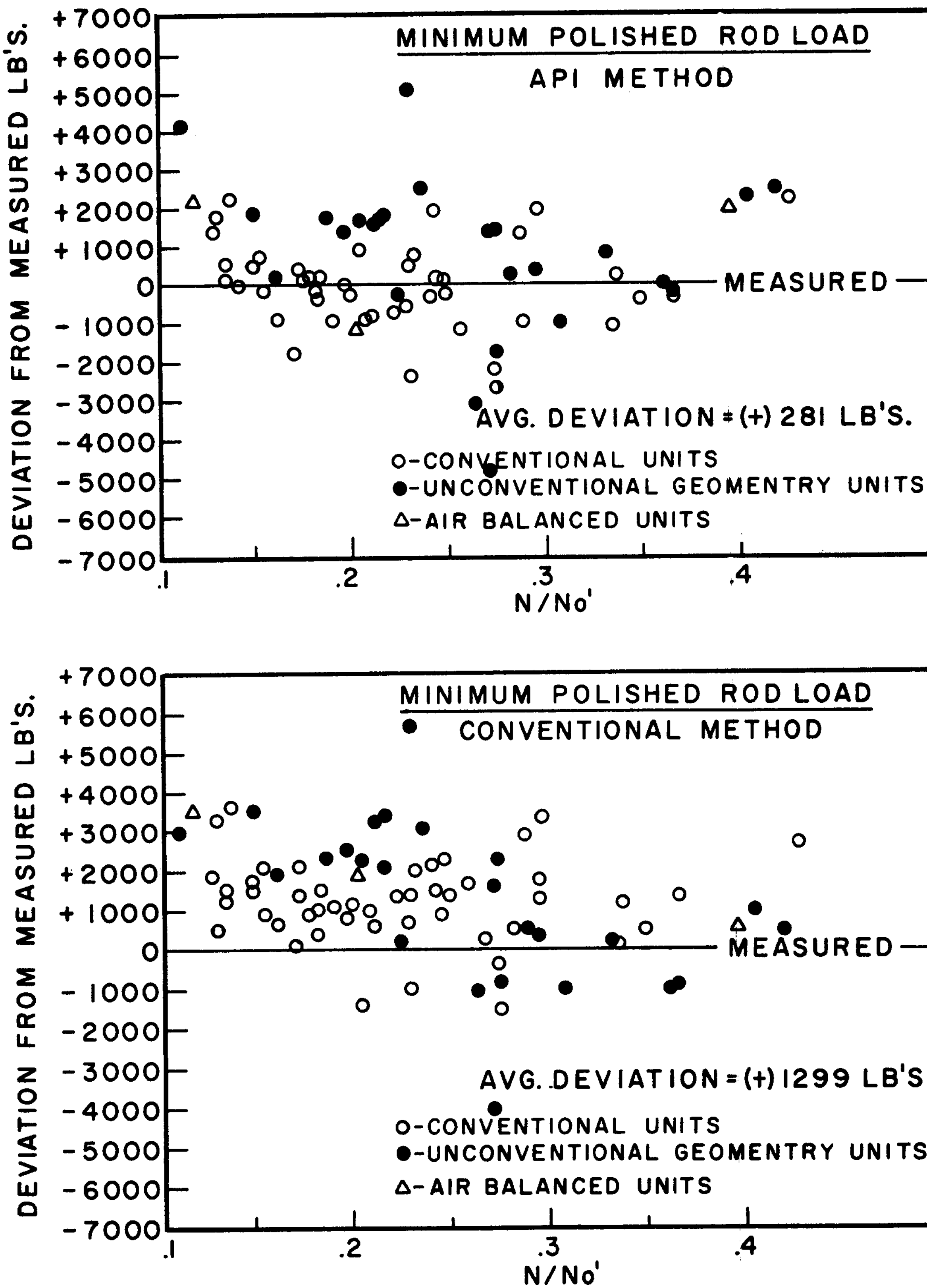
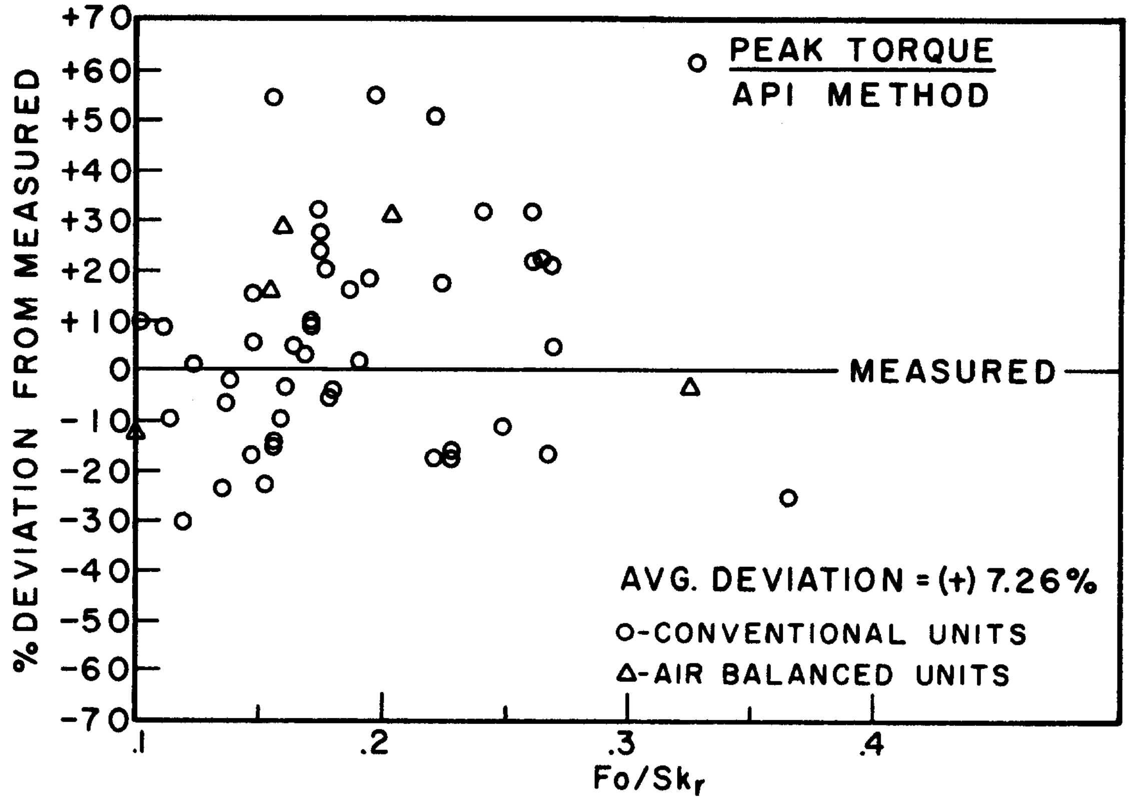

MINIMUM POLISHED ROD LOAD
API METHOD
DEVIATION FROM MEASURED LB'S.
+7000
+6000
+5000
+4000
+3000
+2000
+1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
MEASURED
AVG. DEVIATION = (+) 281 LB'S.
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
N/No'
MINIMUM POLISHED ROD LOAD
CONVENTIONAL METHOD
DEVIATION FROM MEASURED LB'S.
MEASURED
AVG. DEVIATION = (+) 1299 LB'S
O-CONVENTIONAL UNITS
●-UNCONVENTIONAL GEOMENTRY UNITS
Δ-AIR BALANCED UNITS
N/No'

FIGURE 4


PEAK TORQUE
API METHOD
% DEVIATION FROM MEASURED
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
MEASURED
AVG. DEVIATION = (+) 7.26%
O-CONVENTIONAL UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Skr

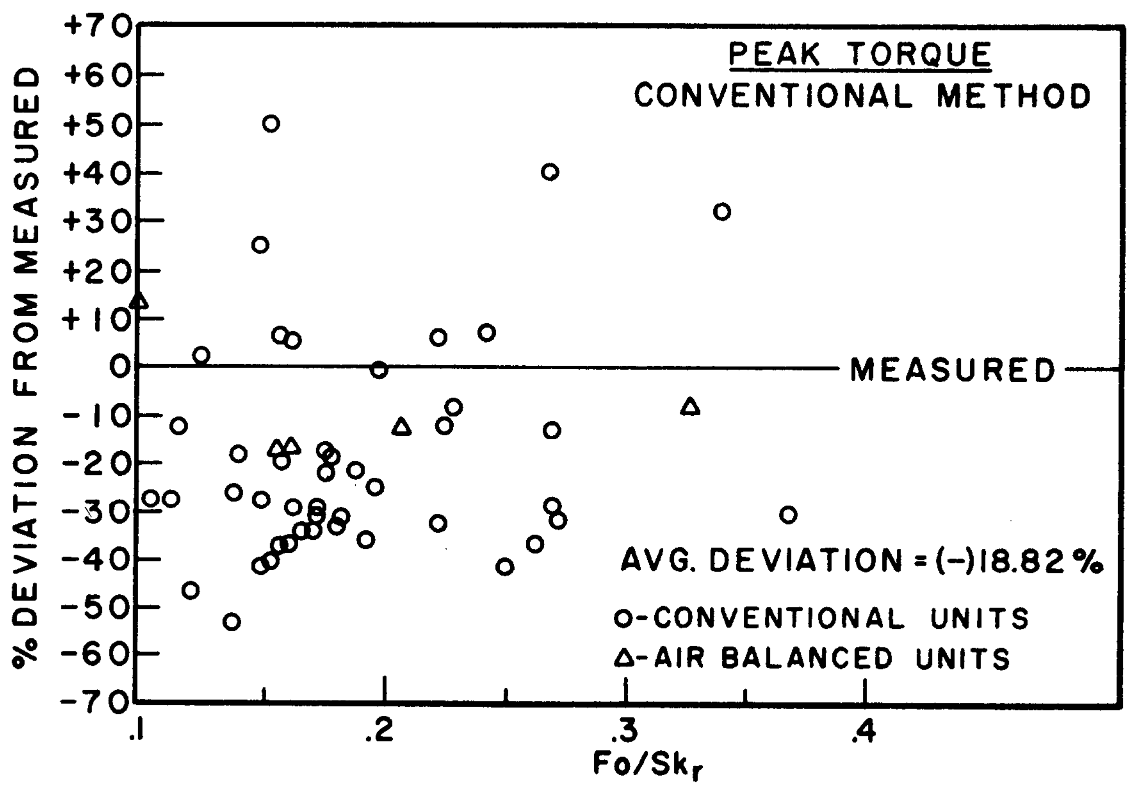
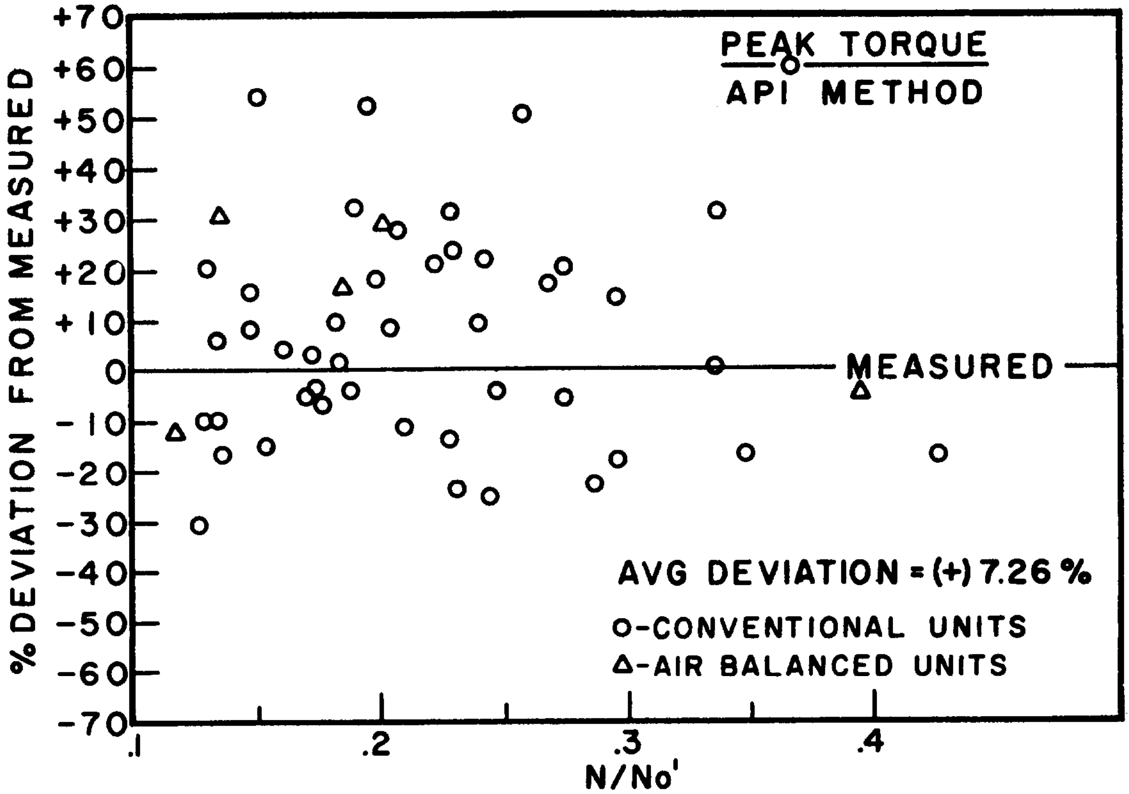

PEAK TORQUE
CONVENTIONAL METHOD
% DEVIATION FROM MEASURED
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
MEASURED
AVG. DEVIATION = (-)18.82%
O-CONVENTIONAL UNITS
Δ-AIR BALANCED UNITS
.1
.2
.3
.4
Fo/Skr

FIGURE 5


PEAK TORQUE
API METHOD
MEASURED
AVG DEVIATION = (+) 7.26 %
O-CONVENTIONAL UNITS
Δ-AIR BALANCED UNITS
% DEVIATION FROM MEASURED
N/No'
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
.1
.2
.3
.4

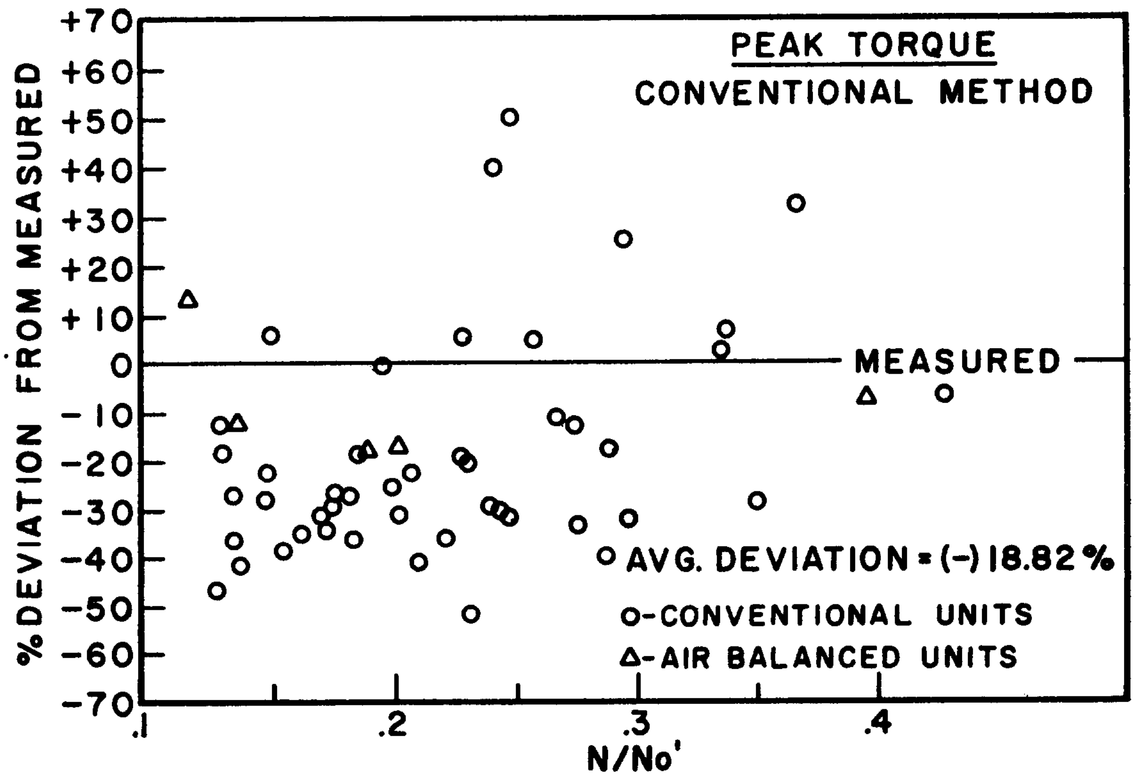

PEAK TORQUE
CONVENTIONAL METHOD
MEASURED
AVG. DEVIATION = (-) 18.82 %
O-CONVENTIONAL UNITS
Δ-AIR BALANCED UNITS
% DEVIATION FROM MEASURED
N/No'
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
.1
.2
.3
.4

FIGURE 6

DEGREE OF DIFFICULTY OF CALCULATIONS

Since the API method takes into account many more variables than does the conventional method, it is more difficult and more time consuming to make the necessary calculations. For one not too familiar with API-RP-11L, or for one who uses it very infrequently, it will take at least three times as long to make the necessary calculations for designing a pumping unit-sucker rod system than does the old conventional way. While it is more accurate, at least to some degree, the increased difficulty in the calculations will limit its universal use unless a computer program is written which will tabulate all the well loads, reducer torques, rod stresses, etc., within some set limits which have been found to be practical. For example, the tabulation would list, say, every 500 ft of depth and in production increments of, say, 100 BPD, all conceivable pumping unit-sucker rod combinations that would satisfy all the limiting conditions of the program. Some of these conditions might be to limit pumping speed to a minimum of 2 or 3 SPM and a maximum of perhaps 20 or 25 SPM. Other limitations would have to be limiting rod stress, a minimum figure for minimum load, etc.

Fortunately, the API has sponsored such a program and is in the process of publishing the results in two different forms. First, it is publishing a series of tabulations as described above in book form (approximately 400 pages). It is also publishing the same information as a bound set of curves. It is the thinking of the members of the API that the tabulation in book form may prove more useful in the selection of new equipment, whereas the curves may be more helpful when pumping units are to be moved from one location to another. This writer believes most production people will want to have access to both publications.

CONCLUSIONS

1. API-RP-11L predicts values for peak polished rod load which are slightly more accurate than the more conventional method of calculations.
2. API-RP-11L predicts values for minimum load which are much more accurate than conventional methods.
3. API-RP-11L predicts gear reducer torques more accurately, due primarily to being able to predict more accurate minimum loads.
4. API-RP-11L makes some broad assumptions in predicting peak torque which can cause considerable error in unit selection:
   (a) The assumption is made that the maximum and minimum loads occur at the 75° and the 285° crank position where the pumping unit torque factors are optimum. Since any calculation for sizing equipment would rarely be made in absence of dynamometer card, this assumption seems valid.
   (b) A pumping unit efficiency of 100 per cent is assumed. A more realistic value in the 90 per cent-95 per cent range should be introduced.
   (c) Perfect counterbalance of the pumping unit is assumed. Years of experience have shown that this is unrealistic. Torque calculations for the gear reducer should include a multiplying factor of 1.2 (in addition to the efficiency factor in (b) above) to compensate for out-of-counterbalance conditions.