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AN ALGORITHM FOR COMPUTING IN-SITU COMBUSTION OIL RECOVERY PERFORMANCE

By
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Stanford University Petroleum Research Institute
Stanford, California

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INTRODUCTION

During in-situ combustion oil recovery, a burning front moves through the formation displacing all of the water and most of the oil in the formation. Often, oil recovery from in-situ combustion is computed considering only the oil displaced by the burning front. This leads to a constant, high value of injected air to oil displaced ratio. The oil displacement is more complex than this simple model indicates. Combustion gas and steam and distilled hydrocarbons move ahead of the burning front. Heat transmission from this vaporizating-condensing region ahead of the burning front, solution of carbon dioxide from the combustion gases, and many other mechanisms are involved in oil displacement. A simple method to consider the frontal displacement, thermally aided gravity drainage, steam distillation, oil swelling and viscosity reduction, and other significant mechanisms ahead of and adjacent to the burning front has been published in a correlation of field and laboratory physical model studies of combustion oil recovery.[1] This method is called the oil-recovery/volume-burned method. This method indicates that the air/oil ratio passes through a minimum, and that oil is recovered more rapidly than is indicated by a simple frontal displacement.

The oil-recovery/volume-burned method can be used to make accurate engineering and economic evaluations for the design and monitoring of in-situ combustion projects. In this paper an algorithm based on this method is presented to provide a quick estimate of the oil recovery, air/oil ratios, oil rates, and economic limits of in-situ combustion projects.

OIL-RECOVERY/VOLUME-BURNED METHOD

Figure 1 is a graph of oil displaced vs volume burned for both laboratory and field combustion experiments.[1] The abscissa represents the percent of the combustion tube's total length travelled by the combustion front in the laboratory or percent of the total pattern volume burned in the field. The percent of total oil displaced is graphed on the ordinate and differs from the original oil in place by the amount of oil consumed as fuel.

The straight, dashed line represents the amount of oil displaced from the burned volume only. However, the data taken in both laboratory and field show higher oil recovery and, therefore, a lower air/oil ratio than indicated by the straight, dashed line. This difference appears to be due to the oil recovery mechanisms of in-situ combustion which affect oil movement ahead of the burning front. These mechanisms include hot water, gas and steam drive, vaporization, miscible displacement, expansion, and gravity drainage. The example cited in Fig. 1 assumed zero gas saturation.

Similar curves can be obtained for different gas saturations. Obviously, a high gas saturation would require a longer fillup time. Figure 2 shows this behavior for several combustion tube runs using

San Ardo crude oil.[2] The ordinate is normalized with respect to consumed fuel to yield total oil displacement at total volume burned. As is shown at the higher gas saturations, the oil recovery curve is straighter. These results also match those previously obtained by Gates and Ramey[1] which are graphed in Fig. 3. Field and laboratory data were combined to obtain the results in Fig. 3. These curves are applicable to heavy oil fields similar to the South Belridge field.

METHODOLOGY

To determine the amount of displaced oil, initial oil and gas saturations must be determined using conventional well logging, coring, material balance or tracer techniques. The displaced oil is the initial oil minus the final oil minus the burned oil. Fuel concentration (C_f) is another important parameter in evaluating an in-situ combustion project. Fluid properties, lithology of formation and operating conditions all affect the value of C_f.

Several methods can be used to estimate C_f. These are described in detail in reference 1. They are: a) coring the reservoir as the combustion progresses; b) measuring the water cut and correlating with C_f by material balance; c) averaging the value of C_f obtained from combustion tube runs with natural core; d) history-matching the combustion behavior in the field using a numerical simulation; and e) using the burning velocity/air flux correlation. In the absence of other data, engineering calculations can be made using correlations of fuel concentration vs oil gravity to determine C_f.[3,4]

To compute the cost of air compression, the value of the combustion air requirement should be determined. This can be calculated if oxygen utilization (U_t) and the volume of air needed to burn a unit weight of fuel (AFR) are known. AFR can be computed from the combustion chemistry.[5] After the burning front breakthrough, more air must be injected to compensate for the air produced because of channeling. Figure 4 is a correlation of excess air with oil recovery.[1] Knowing the AOR, the oil production rate can be determined if the air compressor capacity is known.

The data for air requirement, fuel concentration, initial oil and gas saturations, and oxygen utilization can be combined with an oil-recovery/volume-burned correlation using the following relationships to make an estimate of the potential of an in-situ combustion project.

$$B = \frac{C_f}{\rho_f} \cdot \frac{43560}{350} \tag{1}$$

$$R = S_{oi} - B \tag{2}$$

$$N_p = \frac{N_p,\%}{100} \cdot R \cdot A \cdot H \tag{3}$$

$$\text{Excess air} = \frac{0.9\ (N_p,\%) - 15.85}{100} \tag{4}$$

$$ASR = C_f \cdot AFR\ (43.56) \tag{5}$$

$$\text{Cur. AOR} = \frac{ASR}{\frac{d(N_p,\%)}{d(V_B)} \cdot R} \tag{6}$$

$$\text{Cum. AOR} = \frac{(V_B) \cdot ASR}{N_p} \tag{7}$$

$$\text{Air Required} = \frac{V_B}{100}\ ASR \cdot A \cdot H \tag{8}$$

$$\text{Inj. Air/Prod. Oil} = (\text{Cur. AOR})\left(1 + \frac{\text{Excess air,\%}}{100}\right) \qquad (9)$$

$$\text{Time} = \frac{\text{Air Required}}{(\text{Air Injection Rate})} \qquad (10)$$

where:

A = Pattern Area, acres

AFR = Air/Fuel Ratio, mcf/lb

ASR = Air/Sand Ratio, mcf/ac-ft

B = Fuel Consumed, bbl/ac-ft

C_f = Fuel concentration, lb/cf of rock

Cum. AOR = Cumulative Air/Oil Ratio, mcf, bbl

Cur. AOR = Current Air/Oil Ratio, mcf/bbl

H = Thickness, ft

N_p = Oil Recovered, bbl

N_p,% = Oil Recovered, % of pore volume

R = Ultimate Recovery, bbl/ac-ft

S_{oi} = Initial Oil Saturation, bbl/ac-ft

V_B = Volume Burned, % of bulk volume

ρ_f = Fuel Specific Gravity

To facilitate calculations, the suite of oil-recovered/volume-burned graphs shown on Fig. 3 were curve-matched. It was possible to correlate the lines on Fig. 3 into one curve using non-linear regression method so that only one equation was needed.

CURVE-FITTING PROCEDURE

The first step in developing an algorithm is to curve-fit the oil recovery-volume burned curves shown in Fig. 3. To do this, it was first assumed that the recovery curves could be approximated by straight lines with intercepts $V_B(0)$ at initial oil breakthrough as shown in Fig. 5. By redefining the abscissa as:

$$x = \frac{V_B - V_B(0)}{100 - V_B(0)} \qquad (11)$$

all of the straight lines were put into a single line. Then, a relationship between $V_B(0)$ and gas saturation (Fig. 6) was obtained by curve-fitting:

$$V_B(0) = 0.14714\ S_g + 0.01071\ S_g^2 \qquad (12)$$

The difference between actual oil recovery and estimates obtained from the straight lines was determined. It was found that for each level of gas saturation, there is a maximum calculated deviation (Maximum Deviation). These maxima were correlated with respect to gas saturation (Fig. 7).

$$\text{Maximum Deviation} = 26.8229 - 0.4678\ S_g \qquad (13)$$

The calculated deviations were normalized on the basis of maximum deviations and were graphed with respect to x (Fig. 8). A fourth order polynomial fit the data with the following parameters:

$$\frac{\text{Deviation}}{\text{Maximum Deviation}} = 6.7752\ x - 15.9478\ x^2 + 16.1872\ x^3 - 7.0146\ x^4 \qquad (14)$$

These equations simplify the problem of curve-fitting, and extend the range of applicability of the correlations.

CALCULATOR PROGRAM

the above equations were implemented for us on a Texas Instruments' TI-59 hand-held programmable calculator. This program calculates C_f and AFR from the gas analysis data taken from either the combustion tube or the field. However, if the values of C_f and AFR are available, they can be used independently. Then, cumulative and current AOR, oil recovered, and time are calculated for each burned volume. The program with the supplementary equations and procedure are shown in the Appendix.

COMPARISON OF RESULTS

First, the slope of the oil-recovered/volume-burned correlation was checked for negative values. Then, precautions were taken to prevent both excess air and maximum deviation from having negative answers. When these parameters are less than zero, they will be set to zero. Figure 9 shows the computed results (circles) as well as those of Gates and Ramey[1] (straight lines) for three different gas saturations. In general, the answers are within ±1% of the actual ones.

CONCLUSIONS

An algorithm was developed to estimate the in-situ combustion performance in the field. A calculator program was prepared using this algorithm. The program is efficient, simple and accurate. Given estimates of fuel concentration, air/fuel ratio, gas and oil saturations, and injection rate, for each volume burned, oil recovery, air requirement, and time may be calculated.

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1. Gates, C. G., and Ramey, H. J., Jr.: "A Method for Engineering In-Situ Combustion Oil Recovery Projects," J. Pet. Tech. (Feb. 1980), 285-294.

2. Fassihi, M. R., Ramey, H. J., Jr., and Brigham, W. E.: "The Frontal Behavior of In-Situ Combustion," Paper SPE 8907, presented at the 50th California Regional Meeting of the SPE, Los Angeles, Ca. (April 9-11, 1980).

3. Alexander, J. D., Martin, W. L., and Dew, J. N.: "Factors Affecting Fuel Availability and Composition During In-Situ Combustion," J. Pet. Tech. (Oct., 1962), 1154-1164.

4. Showalter, W. E.: "Combustion Drive Tests," Soc. Pet. Eng. J. (Mar., 1963), 53-58.

5. Nelson, T. W., and McNiel, J. S., Jr.: "How to Engineer an In-Situ Combustion Project," Oil and Gas J. (1961), 39, No. 23, 58.

ACKNOWLEDGEMENT

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APPENDIX A

Table 1 gives the execution procedure for the TI-59 calculator program. Either combustion tube data (steps 4 through 10) or field estimates (steps 12 and 13) may be used for C_f and ASR. If the results for a different volume burned are desired, only step 18 needs to be repeated.

Table 2 is a listing of the data registers after execution of the program. The constants in registers 00-20 are stored on bank 4 of the magnetic cards (Table 3).

Figure 10 is a listing of the calculator program.

Table 4 gives all the equations used in the calculator program.

Table 5 gives the input data and the output from an execution of the program. The data is taken from Ref. 1.

Table 1

PROCEDURE FOR PROGRAM EXECUTION

Step	Procedure	Enter	Press	Display
1	Repartition calculator	4	OP 17	639.39
2	Read magnetic cards		Clr	1,2,3,4
3	If combustion tube data are to be used, continue. If field values are to be used, go to step 12.			
4	Enter tube radius	r_t (ft)	E'	r_t
5	Enter CO_2 concentration	CO_2 (%)	D'	CO_2
6	Enter CO concentration	CO (%)	R/S	CO
7	Enter O_2 concentration	O_2 (%)	R/S	O_2
8	If display value of N_2 is incorrect, enter N_2 concentration	N_2 (%)	R/S	N_2
9	Enter front velocity	V_f (ft/hr)	C'	V_f
10	Enter gas flowrate	q_g (scf/hr)	R/S	ASR
11	Go to Step 14			
12	Enter fuel concentration	C_f (lb/Cf)	B'	C_f
13	Enter air/fuel ratio	AFR (scf/lb)	R/S	ASR
14	Enter field gas saturation	S_g (%)	A'	S_g
15	Enter field oil saturation	S_o (bbl/acre-ft)	A	S_o
16	Enter pattern volume	AH (acre-ft)	B	AH
17	Enter field injection rate	q (mcf/day)	C	q
18	Enter volume burned	V_B, (%)	D	printer output

Table 2

DATA REGISTERS AFTER PROGRAM EXECUTION

Register	Value	Register	Value
00	1541353517	20	7.014659
01	3137001332	21	C_f
02	3500640000	22	ASR
03	1541303040	23	$V_B(0)$
04	13323564	24	x
05	3732371327	25	Maximum Deviation
06	1324350035	26	y
07	1734400064	27	$\frac{dy}{dx}$
08	3224270035	28	Current AOR
09	1715400064	29	Cumulative AOR
10	14142736	30	S_g
11	3724301764	31	R
12	16134536	32	AH
13	0.147143	33	q
14	0.010714	34	V_B
15	26.82295	35	Total AOR
16	0.46787	36	Air Required
17	6.775267	37	N_p,%
18	15.947794	38	N_p
19	16.187187	39	Time

Table 3

CONSTANTS STORED IN BANK 4

1541353517.	00
3137001332.	01
3500640000.	02
1541303040.	03
13323564.	04
3732371327.	05
1324350035.	06
1734400064.	07
3224270035.	08
1715400064.	09
14142736.	10
3724301764.	11
16134536.	12
0.147143	13
0.010714	14
26.82295	15
0.46787	16
6.775267	17
15.947794	18
16.187187	19
7.014659	20
0.	21
0.	22
0.	23
0.	24
0.	25
0.	26
0.	27
0.	28
0.	29

Table 4

CALCULATOR EQUATIONS

$$H/C = \frac{4[0.2658\ N_2 - CO_2 - O_2 - 0.5\ CO]}{CO_2 + CO}$$

$$C_f = \frac{1.209 \times 10^{-3}\ q_g\ [CO_2 + CO][12 + H/C]}{V_f r_t^2}$$

$$AFR = \frac{479.7\ N_2}{(CO_2 + CO)(12 + H/C)}$$

$$ASR = (AFR)C_f(43.56)$$

$$B = (C_f)(124.4)$$

$$R = S_{oi} - B$$

$$V_B(0) = 0.147143\ S_g + 0.010714\ S_g^2$$

$$x = \frac{V_B - V_B(0)}{100 - V_B(0)}$$

$$\text{Maximum Deviation} = \text{M.D.} = 26.82295 - 0.46787\ S_g$$

$$y = \frac{\text{Deviation}}{\text{Maximum Deviation}} = 6.775267\ x - 15.947794\ x^2$$

$$+ 16.187187\ x^3 - 7.014659\ x^4$$

(Table Continued Next Page)

Table 4 (Continued)

$$\text{Slope} = \frac{100}{100 - V_B(0)} + \frac{\text{M.D.}}{100 - V_B(0)} \frac{dy}{dx}$$

$$\text{Current AOR} = \frac{\text{ASR}}{(\text{Slope})(\text{R})}$$

$$N_p,\% = 100\,x + (y)(\text{M.D.})$$

$$N_p = \frac{(N_p,\%)(\text{R})(\text{A})(\text{H})}{100}$$

$$\text{Air Required} = \frac{(\text{ASR})(\text{A})(\text{H})\ V_B}{100}$$

$$\text{Cum. AOR} = \frac{\text{Air Required}}{N_p}$$

$$\text{Time} = \frac{\text{Air Required}}{q}$$

$$\text{Excess Air} = \frac{.9(N_p,\%) - 15.85}{100}$$

$$\text{Total AOR} = \text{Current AOR}(1 + \text{Excess Air})$$

TABLE 5

Input data: C_f = 2.1

AFR = 184.

S_g = 4.

S_o = 1540.

AH = 1.

q = 1.

V_B = 30.

Calculator Output:

```
CURRENT AOR =
 10.72022967

CUMM. AOR=
  7.34770305

TOTAL AOR=
 14.20611437

AIR REQ. =
   5049.4752

OIL REQ. =
 53.74098277     % PV
 687.2181913     BBLS

TIME=
   5049.4752     DAYS
```

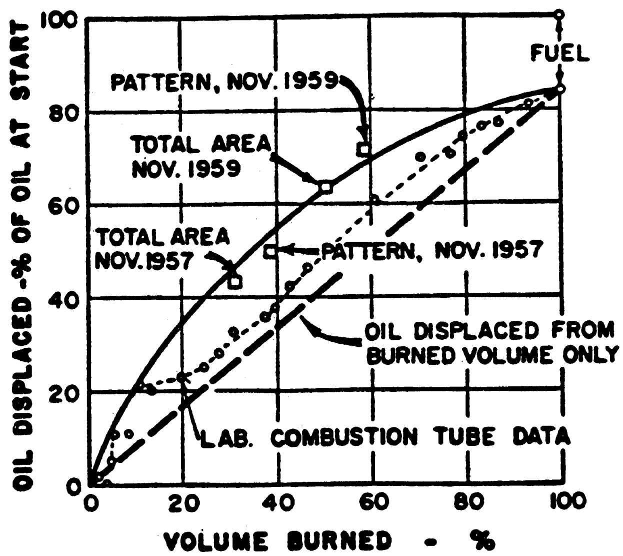

Fig. 1: OIL DISPLACED VS VOLUME BURNED
(From Ref. 1)

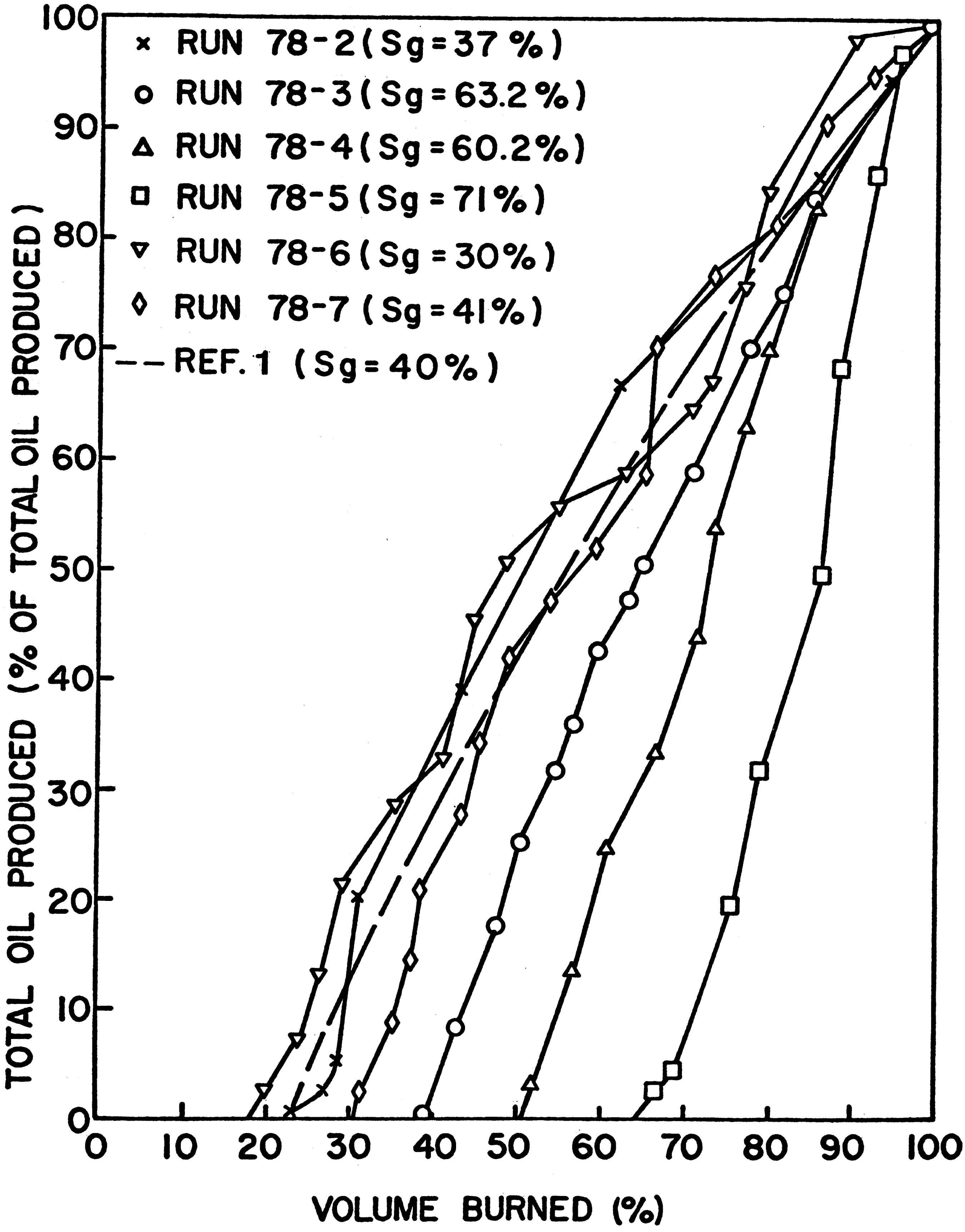

Fig. 2: OIL RECOVERY VS VOLUME BURNED FOR LABORATORY COMBUSTION TUBE RUNS (From Ref. 2)

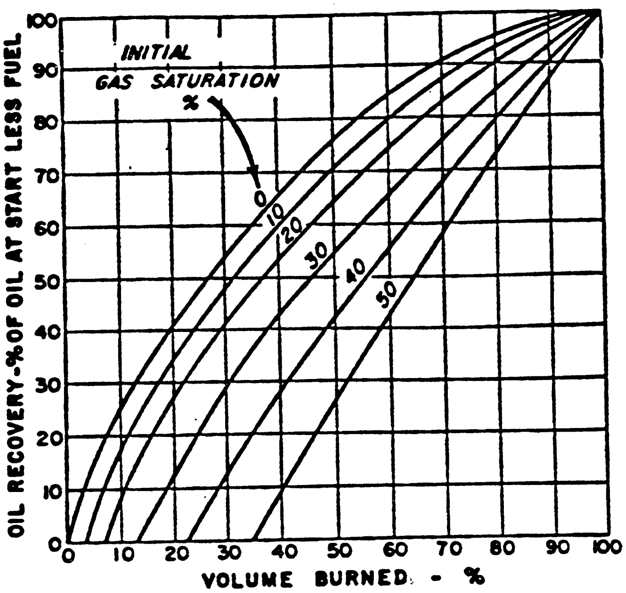

Fig. 3: ESTIMATED OIL RECOVERY VS VOLUME BURNED (From Ref. 1)

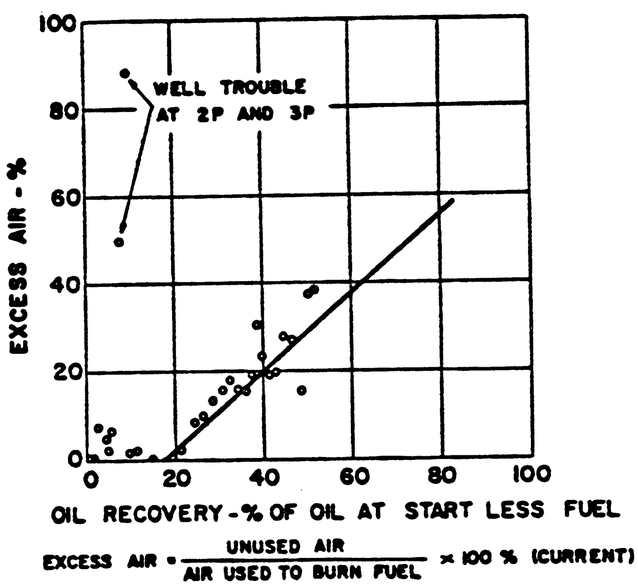

Fig. 4: EXCESS AIR VS OIL RECOVERY (From Ref. 1)

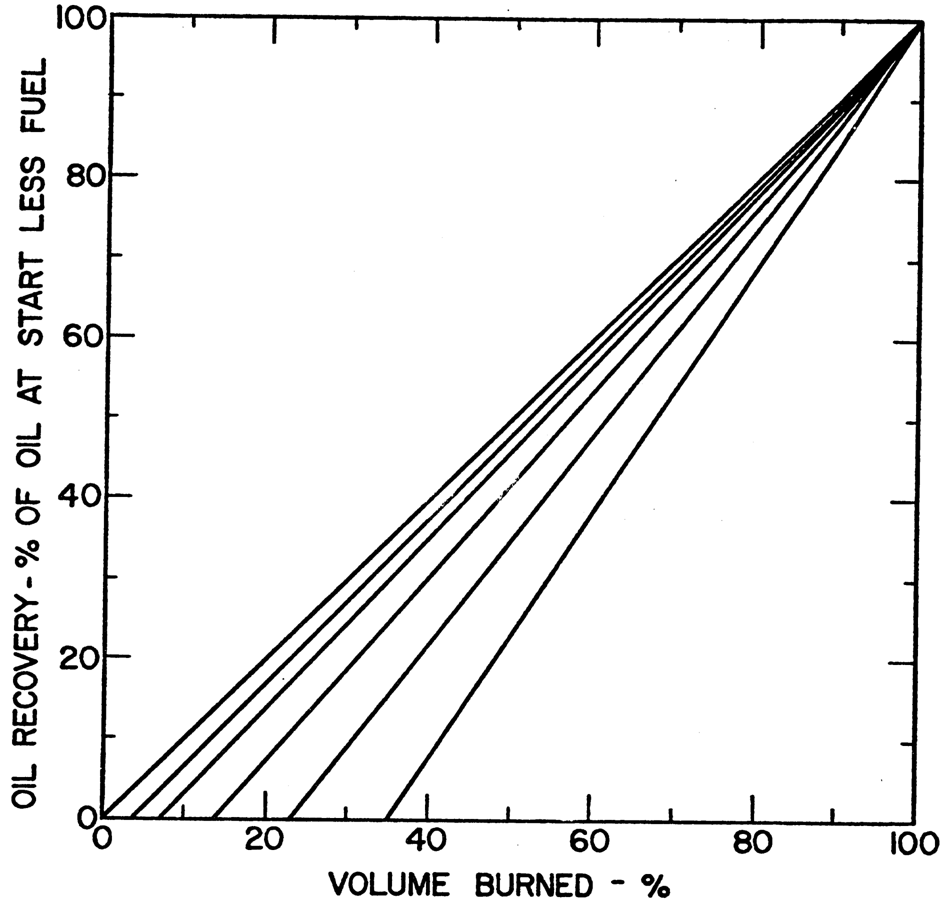

Fig. 5: OIL DISPLACED FROM VOLUME BURNED ONLY

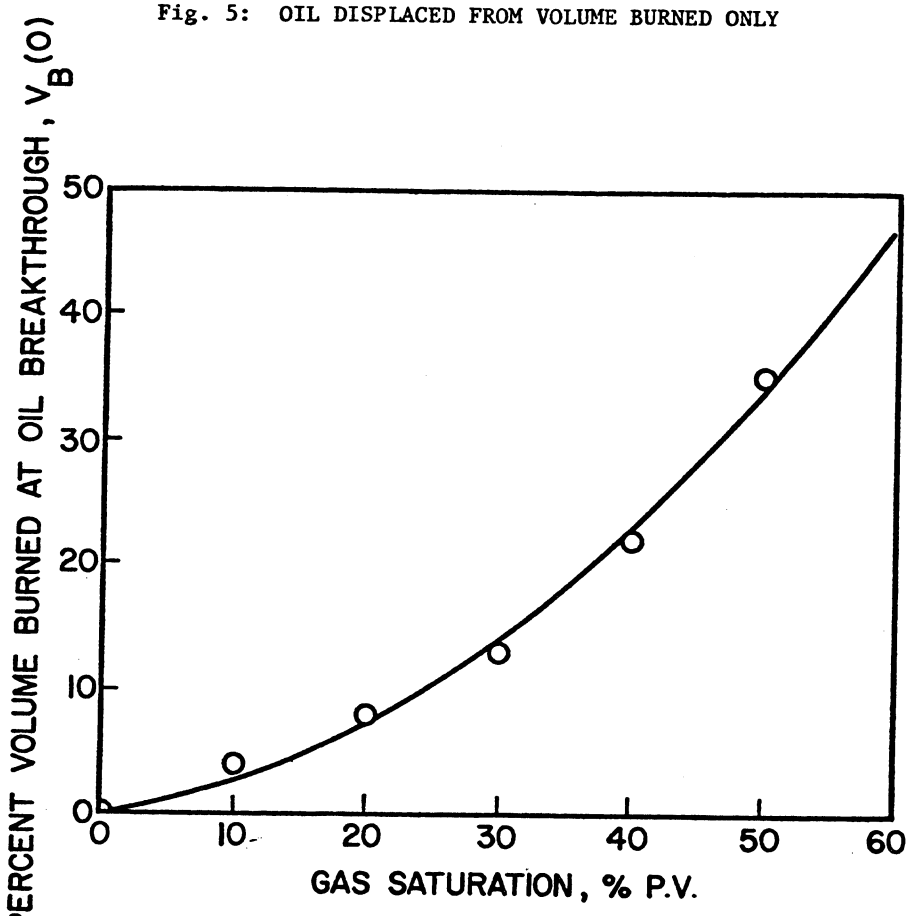

Fig. 6: VOLUME BURNED AT OIL BREAKTHROUGH VS GAS SATURATION

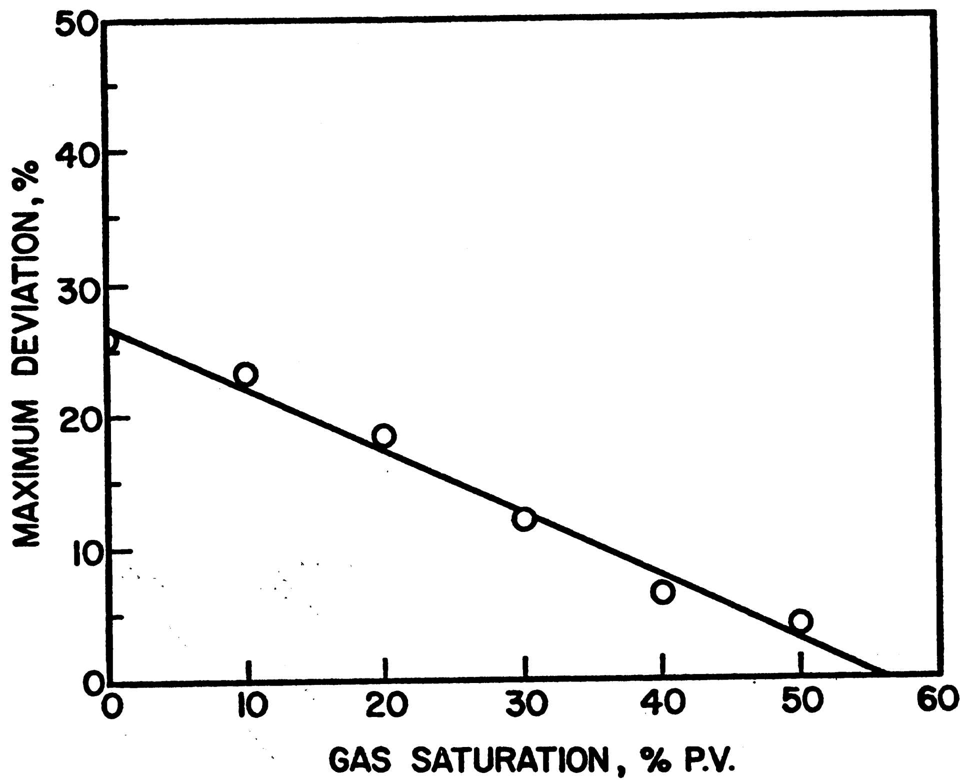

Fig. 7: MAXIMUM DEVIATION VS GAS SATURATION

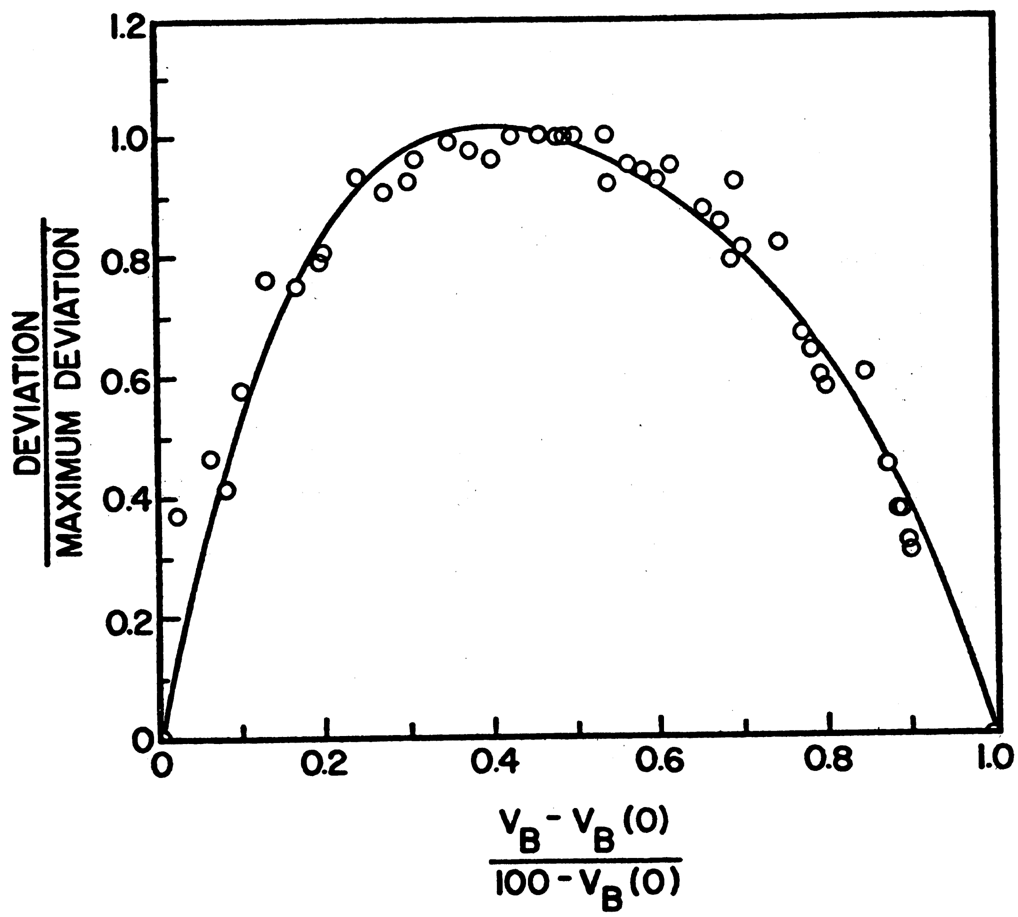

Fig. 8 : NORMALIZED DEVIATION VS NORMALIZED VOLUME BURNED.

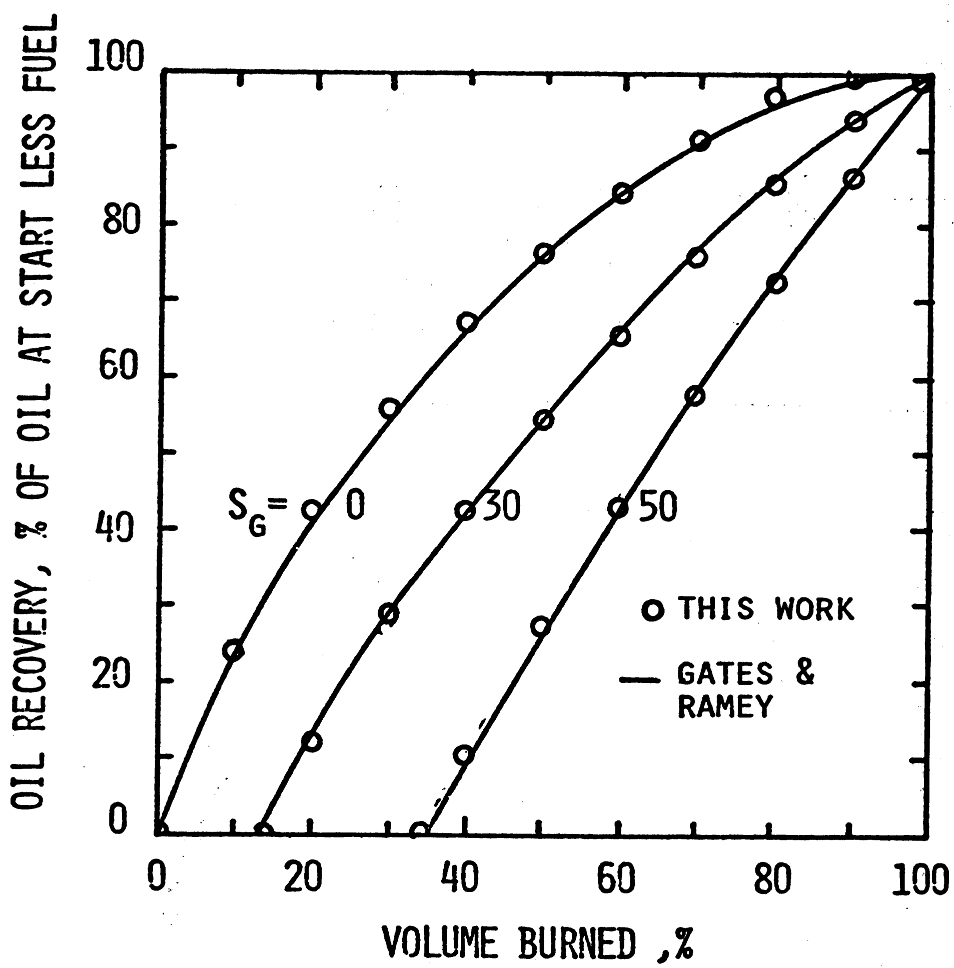

Fig. 9: COMPARISON BETWEEN THIS ALGORITHM AND GATES AND RAMEY'S RESULTS

TITLE ______ PAGE 1 OF 4 — TI Programmable Coding Form

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	10	E'	
002	42	STO	
003	21	21	
004	91	R/S	
005	76	LBL	
006	19	D'	
007	42	STO	
008	22	22	
009	42	STO	
010	24	24	
011	91	R/S	
012	42	STO	
013	23	23	
014	44	SUM	
015	24	24	
016	91	R/S	
017	42	STO	
018	25	25	
019	94	+/-	
020	85	+	
021	09	9	
022	09	9	
023	75	-	
024	43	RCL	
025	24	24	
026	95	=	
027	42	STO	
028	26	26	
029	91	R/S	
030	42	STO	
031	26	26	
032	91	R/S	
033	76	LBL	
034	18	C'	
035	42	STO	
036	27	27	
037	91	R/S	
038	42	STO	
039	28	28	
040	93	.	
041	02	2	
042	06	6	
043	05	5	
044	08	8	
045	65	×	
046	43	RCL	
047	26	26	
048	75	-	
049	43	RCL	
050	22	22	
051	75	-	
052	43	RCL	
053	25	25	
054	75	-	
055	93	.	
056	05	5	
057	65	×	
058	43	RCL	
059	23	23	
060	95	=	
061	65	×	
062	04	4	
063	55	÷	
064	43	RCL	
065	24	24	
066	85	+	
067	01	1	
068	02	2	
069	95	=	
070	42	STO	
071	29	29	
072	65	×	
073	43	RCL	
074	24	24	
075	65	×	
076	43	RCL	
077	28	28	
078	65	×	
079	93	.	
080	00	0	
081	00	0	
082	01	1	
083	02	2	
084	00	0	
085	09	9	
086	55	÷	
087	43	RCL	
088	21	21	
089	33	X^2	
090	55	÷	
091	43	RCL	
092	27	27	
093	95	=	
094	42	STO	
095	21	21	
096	65	×	
097	01	1	
098	02	2	
099	04	4	
100	93	.	
101	04	4	
102	95	=	
103	94	+/-	
104	42	STO	
105	31	31	
106	04	4	
107	07	7	
108	09	9	
109	93	.	
110	07	7	
111	65	×	
112	43	RCL	
113	26	26	
114	55	÷	
115	43	RCL	
116	24	24	
117	55	÷	
118	43	RCL	
119	29	29	
120	65	×	
121	43	RCL	
122	21	21	
123	65	×	
124	04	4	
125	03	3	
126	93	.	
127	05	5	
128	06	6	
129	95	=	
130	42	STO	
131	22	22	
132	91	R/S	
133	76	LBL	
134	17	B'	
135	42	STO	
136	21	21	
137	65	×	
138	01	1	
139	02	2	
140	04	4	
141	93	.	
142	04	4	
143	95	=	
144	94	+/-	
145	42	STO	
146	31	31	
147	43	RCL	
148	21	21	
149	91	R/S	
150	65	×	
151	43	RCL	
152	21	21	
153	65	×	
154	04	4	
155	03	3	
156	93	.	
157	05	5	
158	06	6	
159	95	=	

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62 · 63 · 64 · 72 STO · 73 RCL · 74 SUM · 83 GTO · 84 · 92 INV SBR

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Fig. 10: HAND CALCULATOR PROGRAM

TITLE ______ PAGE 2 OF 4

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
160	42	STD	
161	22	22	
162	91	R/S	
163	76	LBL	
164	16	A'	
165	42	STD	
166	30	30	
167	91	R/S	
168	76	LBL	
169	11	A	
170	44	SUM	
171	31	31	
172	91	R/S	
173	76	LBL	
174	12	B	
175	42	STD	
176	32	32	
177	91	R/S	
178	76	LBL	
179	13	C	
180	42	STD	
181	33	33	
182	91	R/S	
183	76	LBL	
184	14	D	
185	42	STD	
186	34	34	
187	43	RCL	
188	13	13	
189	65	×	
190	43	RCL	
191	30	30	
192	85	+	
193	43	RCL	
194	14	14	
195	65	×	
196	43	RCL	
197	30	30	
198	33	X²	
199	95	=	
200	42	STD	
201	23	23	
202	75	-	
203	43	RCL	
204	34	34	
205	95	=	
206	77	GE	
207	38	SIN	
208	01	1	
209	00	0	
210	00	0	
211	75	-	
212	43	RCL	
213	23	23	
214	95	=	
215	35	1/X	
216	65	×	
217	53	(	
218	43	RCL	
219	34	34	
220	75	-	
221	43	RCL	
222	23	23	
223	54	)	
224	95	=	
225	42	STD	
226	24	24	
227	43	RCL	
228	15	15	
229	75	-	
230	43	RCL	
231	16	16	
232	65	×	
233	43	RCL	
234	30	30	
235	95	=	
236	77	GE	
237	02	02	
238	42	42	
239	00	0	
240	93	.	
241	00	0	
242	42	STD	
243	25	25	
244	43	RCL	
245	17	17	
246	65	×	
247	43	RCL	
248	24	24	
249	75	-	
250	43	RCL	
251	18	18	
252	65	×	
253	43	RCL	
254	24	24	
255	33	X²	
256	85	+	
257	43	RCL	
258	19	19	
259	65	×	
260	43	RCL	
261	24	24	
262	45	YX	
263	03	3	
264	75	-	
265	43	RCL	
266	20	20	
267	65	×	
268	43	RCL	
269	24	24	
270	45	YX	
271	04	4	
272	95	=	
273	42	STD	
274	26	26	
275	43	RCL	
276	17	17	
277	75	-	
278	02	2	
279	65	×	
280	43	RCL	
281	18	18	
282	65	×	
283	43	RCL	
284	24	24	
285	85	+	
286	03	3	
287	65	×	
288	43	RCL	
289	19	19	
290	65	×	
291	43	RCL	
292	24	24	
293	33	X²	
294	75	-	
295	04	4	
296	65	×	
297	43	RCL	
298	20	20	
299	65	×	
300	43	RCL	
301	24	24	
302	45	YX	
303	03	3	
304	95	=	
305	42	STD	
306	27	27	
307	65	×	
308	43	RCL	
309	25	25	
310	55	÷	
311	53	(	
312	01	1	
313	00	0	
314	00	0	
315	75	-	
316	43	RCL	
317	23	23	
318	54	)	
319	85	+	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

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Fig. 10 (Cont.)

TITLE ________ PAGE 3 OF 4 **TI Programmable Coding Form**

PROGRAMMER ________ DATE ________

LOC	CODE	KEY	COMMENTS
320	01	1	
321	00	0	
322	00	0	
323	55	÷	
324	53	(	
325	01	1	
326	00	0	
327	00	0	
328	75	-	
329	43	RCL	
330	23	23	
331	54	)	
332	95	=	
333	77	GE	
334	03	03	
335	39	39	
336	00	0	
337	93	.	
338	00	0	
339	42	STD	
340	28	28	
341	43	RCL	
342	22	22	
343	55	÷	
344	43	RCL	
345	28	28	
346	55	÷	
347	43	RCL	
348	31	31	
349	95	=	
350	42	STD	
351	28	28	
352	01	1	
353	00	0	
354	00	0	
355	65	×	
356	43	RCL	
357	24	24	
358	85	+	
359	43	RCL	
360	25	25	
361	65	×	
362	43	RCL	
363	26	26	
364	95	=	
365	42	STD	
366	37	37	
367	65	×	
368	43	RCL	
369	31	31	
370	65	×	
371	43	RCL	
372	32	32	
373	65	×	
374	93	.	

LOC	CODE	KEY	COMMENTS
375	00	0	
376	01	1	
377	95	=	
378	42	STD	
379	38	38	
380	43	RCL	
381	22	22	
382	65	×	
383	43	RCL	
384	32	32	
385	65	×	
386	43	RCL	
387	34	34	
388	65	×	
389	93	.	
390	00	0	
391	01	1	
392	95	=	
393	42	STD	
394	36	36	
395	55	÷	
396	43	RCL	
397	38	38	
398	95	=	
399	42	STD	
400	29	29	
401	43	RCL	
402	36	36	
403	55	÷	
404	43	RCL	
405	33	33	
406	95	=	
407	42	STD	
408	39	39	
409	93	.	
410	09	9	
411	65	×	
412	43	RCL	
413	37	37	
414	75	-	
415	01	1	
416	05	5	
417	93	.	
418	08	8	
419	05	5	
420	95	=	
421	55	÷	
422	01	1	
423	00	0	
424	00	0	
425	95	=	
426	77	GE	
427	04	04	
428	32	32	
429	00	0	

LOC	CODE	KEY	COMMENTS
430	93	.	
431	00	0	
432	85	+	
433	01	1	
434	54	)	
435	65	×	
436	43	RCL	
437	28	28	
438	95	=	
439	42	STD	
440	35	35	
441	69	DP	
442	00	00	
443	43	RCL	
444	00	00	
445	69	DP	
446	01	01	
447	43	RCL	
448	01	01	
449	69	DP	
450	02	02	
451	43	RCL	
452	02	02	
453	69	DP	
454	03	03	
455	69	DP	
456	05	05	
457	43	RCL	
458	28	28	
459	99	PRT	
460	98	ADV	
461	69	DP	
462	00	00	
463	43	RCL	
464	03	03	
465	69	DP	
466	01	01	
467	43	RCL	
468	04	04	
469	69	DP	
470	02	02	
471	69	DP	
472	05	05	
473	43	RCL	
474	29	29	
475	99	PRT	
476	98	ADV	
477	43	RCL	
478	05	05	
479	69	DP	

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Fig. 10 (Cont.)

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TI Programmable Coding Form

PROGRAMMER ________ DATE ________

LOC	CODE	KEY	COMMENTS
480	01	01	
481	69	OP	
482	05	05	
483	43	RCL	
484	35	35	
485	99	PRT	
486	98	ADV	
487	69	OP	
488	00	00	
489	43	RCL	
490	06	06	
491	69	OP	
492	01	01	
493	43	RCL	
494	07	07	
495	69	OP	
496	02	02	
497	69	OP	
498	05	05	
499	43	RCL	
500	36	36	
501	99	PRT	
502	98	ADV	
503	69	OP	
504	00	00	
505	43	RCL	
506	08	08	
507	69	OP	
508	01	01	
509	43	RCL	
510	09	09	
511	69	OP	
512	02	02	
513	69	OP	
514	05	05	
515	06	6	
516	01	1	
517	00	0	
518	00	0	
519	03	3	
520	03	3	
521	04	4	
522	02	2	
523	69	OP	
524	04	04	
525	43	RCL	
526	37	37	
527	69	OP	
528	06	06	
529	43	RCL	
530	10	10	
531	69	OP	
532	04	04	
533	43	RCL	
534	38	38	

LOC	CODE	KEY	COMMENTS
535	69	OP	
536	06	06	
537	98	ADV	
538	69	OP	
539	00	00	
540	43	RCL	
541	11	11	
542	69	OP	
543	01	01	
544	69	OP	
545	05	05	
546	43	RCL	
547	12	12	
548	69	OP	
549	04	04	
550	43	RCL	
551	39	39	
552	69	OP	
553	06	06	
554	98	ADV	
555	98	ADV	
556	91	R/S	
557	76	LBL	
558	38	SIN	
559	69	OP	
560	00	00	
561	03	3	
562	01	1	
563	03	3	
564	02	2	
565	00	0	
566	00	0	
567	03	3	
568	02	2	
569	02	2	
570	04	4	
571	69	OP	
572	01	01	
573	02	2	
574	07	7	
575	00	0	
576	00	0	
577	01	1	
578	04	4	
579	03	3	
580	05	5	
581	01	1	
582	07	7	
583	69	OP	
584	02	02	
585	01	1	
586	03	3	
587	02	2	
588	06	6	
589	03	3	

LOC	CODE	KEY	COMMENTS
590	07	7	
591	02	2	
592	03	3	
593	03	3	
594	05	5	
595	69	OP	
596	03	03	
597	04	4	
598	01	1	
599	00	0	
600	00	0	
601	04	4	
602	05	5	
603	01	1	
604	07	7	
605	03	3	
606	07	7	
607	69	OP	
608	04	04	
609	69	OP	
610	05	05	
611	98	ADV	
612	98	ADV	
613	98	ADV	
614	91	R/S	

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