

# CHEMICAL PROCESS DESIGN ON A PROGRAMMABLE CALCULATOR

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# **PREFACE**

Rapid advances in semiconductor technology in recent years have brought the small calculator, with significant computational power and at reasonable cost, within reach of every technician or engineer in almost every level of industry. The introduction of the programmable calculator marks a significant advance in this technology and opens a new realm of possibilities to the engineer, student, consultant and teacher—to name just a few. Now the engineer can quickly solve, on a pocket-size calculator, complex and iterative-type problems that were once reserved for very large and complex computers.

This book is intended primarily for, but not limited to, the practicing process engineer who must design and optimize process equipment on a regular basis. A variety of programs are offered that will allow the engineer to look at "what-ifs" in design or sizing alternatives while reducing computational errors. The speed and versatility of the programmable calculator not only provides the user additional time to explore alternative solutions to design problems, but also can play a key role in the stimulation of other ideas.

This book is unique in that sufficient information (equations, theory, background, flowcharts, and instructions) is presented to allow both the TI-59 user and users of other calculators with a different programming language to benefit. Even users of tabletop computers that require BASIC or FORTRAN can readily construct programs from the equations and flowchart logic presented. All programs contain examples that will help the user become thoroughly familiar with the operation of the program.

Most of the programs presented have a self-prompting feature which allows easy use of the programs, by either the novice or the experienced calculator user, with a minimum of instruction. In this mode of operation the calculator asks a series of questions which are answered by the user. When the last question is answered, the calculator will continue through the program to produce a solution to the problem. Although a printer is required to use the self-prompting feature, these programs have been structured to allow easy operation by users without printers. The solutions to all programs, including intermediate results, are stored in data registers for easy recall at the completion of each program. The printed results of each program are formatted so that the tape can be cut and pasted directly onto any associated calculation sheets for a permanent record.

Generally, all programs listed in this book were kept as straightforward and simple as possible. Absolute addressing and indirect addressing were minimized. However, for the most effective use of this material it is assumed that each user has a fairly good working knowledge of his or her calculator.

The book is divided into seven chapters, each of which covers at least one aspect of process design that must be addressed by almost every practicing process engineer at one time or another. All programs presented in this book are based on the experiences of many process engineers for the sizing and optimization of numerous types of process equipment and associated piping. Programs listed cover a wide range of process activities including pipe, pump, and compressor sizing; vessel, dryer, and tower sizing; multicomponent separation; heat transfer, and physical properties of fluids. Several handy utility routines are included that should make life easier for the user.

Programmed magnetic cards for any of the TI-59 programs listed in this book are available for \$7.50 each. Send stamped, self-addressed envelope and blank cards to be programmed to:

W. W. Blackwell 9826 Sagedale Houston, TX 77089

Very special thanks go to Mr. Joe Chao who has offered constructive criticism and many suggestions in the preparation of this book. Joe also wrote the programs for the double-pipe heat exchanger and the two-dimensional linear interpolation that appear in this book.

Special thanks are due my wife Beth for her long and grueling hours at the typewriter trying to decipher my scribblings and extended equations containing unfamiliar symbols in both English and Greek.

W. Wayne Blackwell

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# 1 FLUID FLOW

Typically, process piping costs 20 percent or more of the total plant investment, and energy usage (pressure drop) and continued maintenance add additional costs. It is evident from this that sound sizing practices can have a substantial impact on overall plant economics. Generally, it is the process engineer's responsibility to optimize pressure drop in piping and equipment with compressor or pump horsepower to determine the most economic conditions. This task requires many trial-and-error calculations for which the programmable calculator is well suited.

Several pipe-sizing programs covering a wide range of flow conditions are presented in this chapter. Correlations of both single- and two-phase flow are presented for general line sizing, and a special program for sizing steam condensate headers is included. Pressure drop in packed beds is covered by the familiar Ergun equation, and a comprehensive program is presented for those engineers who must size relief valves for either vapor or liquid service.

A special program for sizing control valves for vapor, liquid, and steam service is included in this chapter as well as a time-saving program for the conversion of pipe fittings to equivalent length of line.

For those users who require the results of these programs in metric units, a conversion table is given in the appendix.

### The Calculation of Compressible Isothermal Flow in Pipelines

It is generally conceded that the flow of a compressible fluid through long pipelines approaches isothermal conditions, i.e., flow at constant temperature. Usually the pressure drop in these pipelines is large relative to the inlet pressure, and because of the appreciable change in density and velocity the usual form of the Darcy pressure-drop equation is not considered applicable. However, an accurate determination of the flow characteristics that apply to this region can be made by applying the complete isothermal equation:

$$w^{2} = \left\{ \frac{144 \ gA^{2}}{V_{1}[FFL/D + 2 \ln (P_{1}/P_{2})]} \right\} \left\{ \frac{P_{1}^{2} - P_{2}^{2}}{P_{1}} \right\}$$
(1-1)

A complete derivation of this equation can be found in an article by Kern.<sup>(1)</sup>

A modification of Eq. (1-1) was programmed to solve for either gas flow or gas pressure at the end of the pipeline. Also programmed was the ideal-gas density equation for rapid calculation of densities when gas molecular weight and temperature are known. Ideal density can be corrected for high-pressure conditions with a compressibility factor. See Chap. 6 for additional information on the calculation of gas density.

The Equations The calculator was programmed to solve the following equations:

$$W = 1337.024 \left\{ \left[ \frac{\rho d^4}{FF12L/d + 2 \ln (P_1/P_2)} \right] \left[ \frac{P_1^2 - P_2^2}{P_1} \right] \right\}^{0.5}$$
 (1-2)

$$P_{2} = \left\{ P_{1}^{2} - \left[ FF12L/d + 2 \ln \frac{P_{1}}{P_{2}} \right] \left[ \frac{W^{2}P_{1}}{\rho d^{4}(1337.024)^{2}} \right] \right\}^{0.5}$$
 (1-3)

$$Re = \frac{6.31W}{d\mu} \tag{1-4}^{(2)}$$

$$FF = \frac{64}{\text{Re}}$$
 for  $\text{Re} \le 2000$  (1-5)<sup>(2)</sup>

$$FF = \left\{ 2 \log \left[ \frac{3.24\varepsilon}{d} + \left( \frac{7}{\text{Re}} \right)^{0.9} \right] \right\}^{-2} \quad \text{for Re} > 2000 \quad (1-6)^{(3)}$$

$$\rho = \frac{(MW)(P)}{RT} \tag{1-7}$$

### NOMENCLATURE

 $P_1$  = initial gas pressure, psia

 $P_2$  = terminal gas pressure, psia

d = pipe inside diameter, in

D = pipe inside diameter, ft

L = pipe length, ft

W = gas flow, lb/h

w = gas flow, lb/s

 $\rho$  = gas density, lb/ft<sup>3</sup>

 $\overline{V}_1$  = specific volume at initial conditions, ft<sup>3</sup>/lb

 $\mu = \text{gas viscosity, cP}$  $\varepsilon = \text{pipe roughness, ft}$ 

MW = molecular weight of gas

P = gas pressure, psia

FF = friction factor

R = gas constant, 10.73

 $T = absolute temperature, {}^{\circ}R$ 

 $g = acceleration of gravity, 32.2 ft/s^2$ 

A =cross-sectional area of pipe,  $ft^2$ 

### Using the Program

Complete operating instructions for this program are shown in Table 1-1. User-defined keys are given in Table 1-2, and data register contents are shown in Table 1-3. The program flowchart is shown in Fig. 1-1. Since the program requires 561 program steps and 40 data registers, the calculator must be partitioned to 639.39 before either stepping in the program or reading it in from prerecorded magnetic cards. The first time the program is stepped into the calculator, certain constants must also be entered into the data registers before the program is stored on magnetic cards. These constants are outlined in Table 1-3.

This program is self-prompting, and once the correct label is pressed the user need only answer the questions presented and continue the program by pressing R/S.

Label  $\underline{A}$  will calculate the maximum gas flow rate for a given line size and pressure drop. Label  $\underline{B}$  will calculate the terminal pressure in a given size pipeline with a known gas flow rate, and label  $\underline{C}$  will calculate the ideal-gas density.

After all questions have been answered, the calculator proceeds to carry out the computations to produce the solution. Users operating this program without a printer can follow the instructions given in Table 1-1 to enter data. The final answer is displayed and intermediate results are stored in data registers as shown in Table 1-3.

### 4 Chemical Process Design on a Programmable Calculator

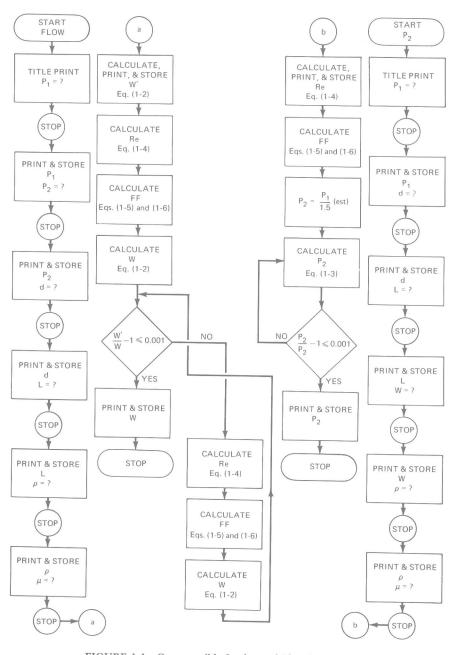


FIGURE 1-1 Compressible Isothermal Flow in Pipelines

此为试读,需要完整PDF请访问: www.ertongbook.com

TABLE 1-1 User Instructions

Step	Procedure	Enter	Press	Display
1	Partition calculator	4	2d Op 17	639.39
	at 639.39			
2	Load program	Side 1		1
	1 0	Side 2		2
		Side 3		3
		Side 4		4
	ISC	THERMAL FLO	)W	
3	Press label A		A	2413007100
4	11035 141501 11	$P_1$	R/S	3303003336
5		$p_2$	R/S	7100000000
6		d	R/S	2700213700
7		L	R/S	6315210071
8		ρ	R/S	3300710000
9		$\mu$	R/S	Flow, lb/h
	10	sothermal $\Delta$	P	
9		SOTHERMAL D	В	2413007100
3	Press label <u>B</u>	$P_1$	R/S	7100000000
4		d	R/S	2700213700
5 6		L	R/S	2335007100
()		L		
		W	R/S	6315210071
7		W	R/S R/S	
		$W \\  ho \\ \mu$	R/S R/S R/S	6315210071 3300710000 P <sub>2</sub> , psia
7 8	rn.	$ ho \mu$	R/S R/S	3300710000
7 8 9		ρ	R/S R/S	3300710000 P <sub>2</sub> , psia
7 8 9	Press label <u>C</u>	ρ μ EAL-GAS DENS	R/S R/S	$P_2$ , psia
7 8 9		ρ μ EAL-GAS DENS	R/S R/S SITY C R/S	3300710000 P <sub>2</sub> , psia  3043007
7 8 9		ρ μ EAL-GAS DENS	R/S R/S	3300710000

TABLE 1-2 User-Defined Keys

Label	Label Function
A	Calculates the maximum gas flow rate in pipelines for a given
_	pipe size and pressure drop.
В	Calculates the terminal pressure in a given size pipeline with a
_	known gas flow rate.
C	Calculates the ideal-gas density of a gas.

TABLE 1-3 Data Registers

Data register no.	Information stored	Units	
00	Not used		
01	$P_1$	psia	
02	$P_2$	psia	
03	d	in	
04	L	ft	
05	W	lb/h	
06	ρ	lb/ft <sup>3</sup>	
07	$\mu$	cP	
08	$\frac{12L}{d}$		
09	$2 \ln \frac{P_1}{P_2}$		
10	$FF\frac{12L}{d}$		
11	Re		
12	FF		
13	$0.00015(\epsilon)^*$	ft	
14	1337.024 (constant)*		
15	$d^4 \left( P_1^2 - P_2^2 \right) \left( \frac{1}{P_1} \right)$		
16	0.013 (initial <i>FF</i> )*		
17	0.001 (tolerance)*		
18	$P_1^2$		
19	$W^2 \left( \mathrm{P}_1 \right) \left( \frac{1}{oldsymbol{ ho}_d^4} \right)$		
20	2436323723*	Print codes	
21	1735301327*		
22	21273243*		
23	3302003336*		
24	2413007100*		
25	3303003336*		
26	1600243100*		
27	7100000000*		
28	2700213700*		
29	4300271463*		
30	2335007100*		
31	4224360015*		
32	3300710000*		
33	75330000*		
34	1631002714*		
35	6315210071*		

Data register no.	Information stored	Units
36	30430071*	
37	330071*	
38	3765210071*	
39	51631521*	*

**TABLE 1-3 Data Registers (Continued)** 

### Examples

- 1. What is the maximum flow rate for a pipeline that is 100 miles (528,000 ft) long and has an internal diameter of 13.376 in? Gas enters the pipeline at 1300 psia and exits at 300 psia. The flowing gas has a density of 4.87 lb/ft<sup>3</sup> and a viscosity of 0.011 cP.
- 2. Assuming the same gas flow rate as Prob. 1, what is the gas pressure after 50 miles (264,000 ft)?
- 3. What is the ideal density of the gas at the end of the pipeline if the gas molecular weight is 20.1 and the flowing temperature is 40°F?

**Procedure** Press label A and answer the questions for solution 1, press label B and answer the questions for solution 2, and finally press label C and answer the questions for solution 3. After an answer to each question has been keyed into the calculator, the program is continued by pressing the R/S key.

Shown below are the solutions to these problems.

Solution 1 (label $\underline{\mathbf{A}}$ )	Solution 2 (label $\underline{\mathbf{B}}$ )	Solution 3 (label C)			
ISOTHERMAL FLOW	ISOTHERMAL "P	DN LB/CF ?			
P1 PSIA ?	P1 PSIA ?	MW ?			
1300.	1300.	20. 1			
P2 PSIA ? 300.	D IN ? 13.376	P ? 300.			
700. T IN ?	L FT ?	T'F ?			
13.376	528000.	40.			
L FT ?	W LB/HR ?	1.123951538 */CF			
528000.	237117.6797				
DN LB/CF ?	DN LB/CF ?				
4.87	4.87				
VIS CP ?	VIS CP ?				
0.011	0.011				
W LB/HR ?	P2 PSIA ?				
237117.6797	300.001095				

<sup>\*</sup> Data which must be stored in data registers the first time the program is stepped into the calculator and before the program is stored on magnetic cards. Contents in registers 13, 16, and 17 may be varied by the user.

### 8 Chemical Process Design on a Programmable Calculator

## PROGRAM LISTING Compressible Isothermal Flow

# PROGRAM LISTING Compressible Isothermal Flow

188	69 OP	235	43 RCL	282	05 05	329	95 =
189	00 00	236	28 28	283	91 R/S	330	42 STO
190	43 RCL	237	69 DP	284	42 STO	331	iō Tiō
191	20 20	238	01 01	285	07 07	332	43 RCL
192	69 DP	239	69 DP	286	99 PRT	333	01 01
193	01 01	240	05 05	287	43 RCL	334	55 ÷
194	43 RCL	241	91 R/S	288	01 01	335	
195	21 21	242	42 STD	289	33 X2	336	93 .
196	69 DP	243	04 04	290	42 STO	337	05 5
197	02 02	244	99 PRT	291	18 18	338	95 =
		245	43 RCL	292	43 RCL	339	42 STO
198	43 RCL			274			
199	33 33	246	29 29	293	05 .05	340	02 .02
200	69 DP	247	69 DP	294	33 X2	341	76 LBL
201	03 03	248	01 01	295	65 ×	342	29 CP
202	69 DP	249	43 RCL	296	43 RCL	343	43 RCL
203	05 05	250	30 30	297	01 01	344	01 01
204	98 ADV	251	69 DP	298	55 ÷	345	55 +
205	69 DP	252	02 02	299	43 RCL	346	43 RCL
206	00 00	253	69 DP	300	06 06	347	02 02
		254	05 05	301	55 ÷	348	95 =
207	43 RCL		91 R/S				
208	23 23	255		302		349	
209	69 DP	256	42 STD	303	03 03	350	65 X
210	01 01	257	05 05	304	33 X2	351	02 2
211	43 RCL	258	99 PRT	305	33 X2	352	95 =
212	24 24	259	43 RCL	306		353	55 +
213	69 DP	260	34 34	307	43 RCL	354	43 RCL
214	02 02	261	69 DP	308	14 14	355	10 10
215	69 DP	262	01 01	309	33 X2	356	95 =
216	05 05	263	43 RCL	310	95 =	357	65 ×
217	91 R/S	264	35 35	311	42 STD	358	43 RCL
218	42 STD	265	69 DP	312	19 19	359	19 19
219	01 01	266	02 02	313	43 RČL	360	95 =
220	99 PRT	267	69 DP	314	04 04	361	94 +/-
221	43 RCL	268		315	65 X	362	
222	26 26	269	91 8/5	316	01 1	363	43 RCL
223	69 OP	270	42 STD	317	02 2	364	18 18
224	01 01	271	06 06	318	55 ÷	365	95 =
225	43 RCL	272	99 PRT	319	43 RCL	366	34 FX
226	27 27	273	43 RCL	320	03 03	367	48 EXC
227	69 DP	274	31 31	321	95 =	368	02 02
228	02 02	275	69 DP	322	42 STO	369	55 ÷
229	69 DP	276	01 01	323	08 08	370	43 RCL
230	05 05	277	43 RCL	324	71 SBR	371	02 02
231	91 R/S	278	32 32	325	35 1/X	372	75 -
		279	69 DP	326	65 X	373	
232							
233	03 03	280	02 02	327	43 RCL	374	95 =
234	99 PRT	281	69 DP	328	08 08	375	50 I×I

## 10 Chemical Process Design on a Programmable Calculator

# PROGRAM LISTING Compressible Isothermal Flow

376 32 X;T 423 25 CLR 470 08 08 517 69 0P 377 43 RCL 424 06 6 471 85 + 518 03 03 378 17 17 425 04 4 472 43 RCL 519 69 0P 379 22 INV 426 55 + 473 09 09 520 05 05 380 77 GE 427 43 RCL 474 95 = 521 91 R/S 381 29 CP 428 11 1 475 35 1/X 522 99 PRT 382 43 RCL 429 95 = 476 65 × 523 49 PRD 383 25 25 430 42 STD 477 43 RCL 524 06 06 384 69 0P 431 12 12 12 478 15 15 525 69 0P 385 01 01 432 76 LBL 479 95 = 526 00 00 386 43 RCL 433 25 CLR 480 34 FX 527 43 RCL 387 24 24 434 07 7 481 65 × 528 38 38 388 69 0P 435 55 + 482 43 RCL 529 69 0P 389 02 02 436 43 RCL 483 14 14 530 03 03 390 69 0P 437 11 11 484 95 = 531 69 0P 391 05 05 438 95 = 485 92 RTN 532 05 05 392 43 RCL 439 45 YX 486 76 LBL 533 91 R/S 393 02 02 440 93 . 487 13 C 534 99 PRT 394 99 PRT 441 09 9 488 69 0P 534 99 PRT 395 98 RDV 442 95 = 489 00 00 536 04 4 396 98 RDV 443 85 + 490 43 RCL 537 06 0 398 76 LBL 445 93 . 492 69 0P 539 95 = 390 351 XX 446 02 2 493 02 02 540 64 4 397 91 R/S 444 03 3 491 34 34 538 00 0 398 76 LBL 445 93 . 492 69 0P 539 95 = 390 351 XX 446 02 2 493 02 02 540 60 6 402 65 × 449 43 RCL 496 69 0P 543 93 7 7 404 93 . 451 555 + 498 69 0P 554 03 3 405 06 6 450 13 13 497 03 03 544 07 7 404 93 . 451 555 + 498 69 0P 554 03 3 405 07 07 459 33 X2 506 03 03 553 04 04 407 55 + 454 95 = 501 69 0P 554 39 39 411 11 11 48 49 43 RCL 541 01 1 401 05 5 + 454 95 = 501 69 0P 554 03 3 405 03 3 452 43 RCL 496 69 0P 554 03 3 406 01 1 453 03 03 500 98 RDV 47 22 INV 407 55 + 454 95 = 501 69 0P 554 43 RCL 410 42 STD 461 42 STD 508 05 555 66 09 0P 413 95 = 460 35 1/X 507 69 0P 554 43 RCL 410 42 STD 461 42 STD 508 05 555 66 06 06 415 11 11 462 12 12 509 91 R/S 556 09 0P 417 02 2 464 76 LBL 511 06 06 558 98 RDV 418 00 0 466 43 RCL 513 69 0P 559 98 RDV 419 00 0 466 43 RCL 513 69 0P 559 98 RDV 419 00 0 466 43 RCL 513 69 0P 550 98 RDV 419 00 0 466 43 RCL 513 69 0P 550 98 RDV 419 00 0 466 43 RCL 513 69 0P 550 98 RDV 419 00 0 466 43 RCL 513 69 0P 550 98 RDV 420 20 10 467 12 12 514 00 00 561 91 R/S								
377	974	OO WAT	400	commence of the	4 72 75	.mmmm.		
377 43 RCL 424 06 6 471 85 + 518 03 03 378 17 17 425 04 4 472 43 RCL 519 69 DP 330 77 GE 427 43 RCL 474 95 = 521 91 R/S 381 29 CP 428 11 11 475 35 1/X 522 99 PRT 383 25 25 430 42 STD 477 43 RCL 524 06 06 384 69 DP 431 12 12 478 15 15 525 69 DP 385 01 01 432 76 LBL 479 95 = 526 00 00 386 43 RCL 433 25 CLR 480 34 FX 527 43 RCL 387 24 24 434 07 7 481 65 × 528 38 38 38 38 69 DP 435 55 ÷ 482 43 RCL 529 69 DP 389 02 02 436 43 RCL 483 14 14 530 03 03 386 69 DP 437 11 11 484 95 = 531 69 DP 391 05 05 438 95 = 485 92 RTN 532 05 05 392 43 RCL 439 45 FX 486 76 LBL 533 91 R/S 393 02 02 440 93 . 487 13 C 534 99 PRT 391 05 05 438 95 = 485 92 RTN 532 05 05 392 43 RCL 439 45 FX 486 76 LBL 533 91 R/S 393 02 02 440 93 . 487 13 C 534 99 PRT 395 98 RDV 443 85 + 490 43 RCL 537 06 6 397 91 R/S 444 03 3 491 54 538 00 0 536 04 4 470 42 95 = 489 00 00 536 04 4 43 94 578 444 03 3 491 578 578 66 69 DP 375 85 FX 444 03 3 491 578 678 678 147 04 4 494 43 RCL 537 06 6 6 397 91 R/S 393 02 02 446 03 13 13 497 03 03 544 07 7 3 491 678 678 678 678 678 678 678 678 678 678							517	69 DP
378	377	43 RCI	494	DE E	471	(D) Eq. (4.	EE 4 (*)	
379								
379				U4 4	472	43 RCL	1519	69 NP
380	379	22 TNW	496	E., E.,	470	na na		
381 29 CP								
381 29 CP			427	43 RCL	474	95 =	521	91 R/S
382	381	29 CP	422	11 11	475			
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