N86-14096

SPARGER SYSTEM FOR MMH-HELIUM VENTS

Based on a calculated vent flow rate and MMH concentration, a TI-59 program was run to determine total sparger hole area for a given sparger inlet pressure. Hole diameter is determined from a mass transfer analysis in the holding tank to achieve complete capture of MMH. In addition, based on oxidation kinetics and vapor pressure data, MMH atmospheric concentrations are determined 2 ft above the holding tank.

By: A. Rakow

CONTENTS

A. MMH Vent Rates

A typical venting profile is given on the attached TPS. With 800 gallons of ullage and the assumption of ideal bahavior (in this pressure range helium exhibits heating rather than cooling upon expansion, but only about 0.06°C per atm; therefore, isothermal expansion is reasonable) the volumetric rate would be 1459 scfm during the first 10 seconds. With a vapor pressure of 0.957 psia the MMH concentration would be about 3400 ppm. At the completion of the vent the rate would be about 162 scfm and the concentration (assuming rapid vapor equilibrium during venting) 16,780 ppm.

For the purpose of designing a sparger, let's take 1500 scfm as the max flow and 100 psi as the sparger inlet pressure (either an analysis of Δ P in the vent system or pressure measurement during a vent is necessary to determine this parameter).

For the purpose of analysing dispersion of MMH to the atmosphere above the holding tank, we need to estimate the total amount of MMH vented. The average flow rate is 800 scfm for 3 minutes, i.e., we're venting 2400 scf which is 6.7 lb moles. At an average concentration of about 10,000 ppm MMH, we would be venting 0.067 lb moles of MMH.

B. Sparger Program

The attached sparger program will determine the total hole area and area distribution required for a liquid sparger.

Since our case is a gas dispersed into a liquid phase, we have to employ the gas orifice equation instead of equation (9) in the attached article by Mink.

The gas orifice equation:

$$W = 1891\ Y\ d_o^2\ C \left(\frac{\Delta P}{V_1}\right)^{\frac{1}{2}}$$

Where
W = lb/hr
ΔP = psi
V_1 = ft^3/lb
d_o = orifice diameter, in.

converts to

$$a = \frac{.26}{1830}\ \frac{Q}{\left[\ \Delta P/\rho\ \right]^{\frac{1}{2}}}$$

using a value of 0.6 for both Y and C.

Therefore, equation (9) in the article by Mink probably overpredicts the area by a factor of 4. Keeping this in mind, the conditions of 1500 scfm and 100 psi were run, giving the following results:

For A = 11,220 GPM
B = 100 psi
C = 20 psi (includes 9-ft head in tank)
D = 2 inches (Sparger I.D.)
A' = 0.011
B' = 0.011
C' = 7 ft

$a = 0.72\ \text{in}^2$

Since this is an overprediction, we probably only need 0.18 in^2 total hole area (of course, it is extremely important to know the actual sparger inlet pressure; our value of 100 psi is used for illustrative purposes).

C. Mass Transfer Analysis in Holding Tank

1. Rate

The mass transfer rate to the tank can be approximated by:

$$N_A = \sqrt{\frac{4 D_{AB}\ V_t}{\pi\ d_p}}\ C_{A_o}$$

Where $N_A = \frac{\text{g moles}}{\text{CM}^2\ \text{sec}}$ MMH transfered to water

D_{AB} = diffusivity of MMH in H_2O
V_t = terminal velocity of rise of drop
C_{A_o} = solubility of MMH in H_2O in moles/volume
d_p = drop diameter

In order to use this equation we need to determine the drop diameter, d_p, and the terminal velocity.

The terminal velocity is given by:

$$V_t = \sqrt{\frac{2\sigma g_c}{d_p\ \rho_\ell} + \frac{g\ d_p}{2}}$$

Where σ is the surface tension of water and ρ_ℓ is liquid density.

The particle (drop) diameter in inches is given by:

$$d_p = 0.279\ (Re_o)^{-0.05}$$

based on a jet correlation (p. 141, Treybal).

Using an upper limit of 50,000 on Re_o, we get 0.16 inches for the bubble diameter. This gives a value of 0.77 ft/sec for V_t.

Plugging these values into the equation for N_A gives a very high rate of mass transfer indicating that most, if not all of the MMH, should be absorbed.

2. Orifice Diameter and Number of Holes

$$\text{The orifice Reynolds's number } Re_o = \frac{d_o \ V_o \ \rho}{\mu}$$

Where V_o is the velocity in the orifice and ρ and μ are density and viscosity, respectively.

Using the criterion of $Re_o = 50{,}000$, we get the following two equations:

For 1500 scfm

1. $n \, d_o = 11.36$

2. $\pi \left(\frac{d_o}{2}\right)^2 n = a = 0.18 \text{ in}^2$

where n = no. of holes

Therefore $\frac{\pi d_o}{4} (11.36) = 0.18$

or $d_o = 0.020$ inches

$\therefore n = 568$

So <u>568 holes</u> at <u>0.02 inches</u> per hole (<u>1/50</u>") should do the job in this case.

D. Mass Transfer Analysis from Tank to Atmosphere

This analysis is based on the following assumptions:

1. 0.067 lb moles of MMH are completely absorbed from the sparger during a vent in a well mixed tank of water 10' X 5' X 9' filled to the 6-foot level.

2. MMH is depleted by two mechanisms
   a. diffusion from the gas liquid interface through 3 ft of air to the top of the tank where it is swept away (zero concentration at top)
   b. in the tank MMH disappears by oxidation at a rate of 100 ppm/day (This number is an average of open pan tests done by Eric Miller and data in the Florida Tech handbook.)

3. the Henry's law relationship for MMH is $y = mx$, where $m = 0.05$, and y and x are the mole fractions of MMH in air and H_2O, respectively

4. equilibrium exists at the gas liquid interface

5. diffusion in the gas phase is quasi-steady and unidirectional

First, let's compute the initial mole fraction of MMH in the tank, X_{ℓ_0}, in ppm:

$$300\ \text{ft}^3\ H_2O \times 62.4\ \frac{\text{lb}}{\text{ft}^3} \times 1\ \frac{\text{lb mole}}{18\ \text{lb}} = 1040\ \text{lb moles}\ H_2O$$

$$\frac{.067}{1040} = 64\ \text{ppm} = X_{\ell_0}$$

The diffusion rate in the gas phase is given by

$$N_A = \frac{\mathcal{D}_{\text{MMH-Air}}\ A\ C\ (0.05)(X_\ell)}{\ell}$$

Where N_A - flux in moles/area time
$\mathcal{D}_{\text{MMH-Air}}$ - diffusivity of MMH in air
A - cross sectional area of tank
C - gas molar density
X_ℓ - mole fxn of MMH in tank at any time, t
ℓ - distance between the gas-liquid interface and the top of the tank

Using a value of $0.2\ \text{cm}^2/\text{sec} = 0.775\ \frac{\text{ft}2}{\text{hr}}$

for $\mathcal{D}_{\text{MMH-Air}}$ we get

$$N_A = 0.00177\ X_\ell(t)\ \frac{\text{moles}}{\text{hr}}$$

Now we can write a mass balance for MMH in the tank to compute X_ℓ as a function of time, t.

rate of accumulation = - rate of depletion - rate at which MMH leaves
of MMH in tank by oxidation thru interface

or

$$1040\ \frac{dX_\ell}{dt} = \frac{-10^{-4}\ (1040)}{\text{day}} \cdot \frac{1\ \text{day}}{24\ \text{hours}} - 0.00177X_\ell$$

where t is in hours

The solution to this equation is:

$$X_\ell = 2.35(e^{-1.7 \times 10^{-6}t} - 1) + X_o\, e^{-1.7 \times 10^{-6}t}$$

or $$X_\ell = (X_{\ell_0} + 2.35)(e^{-1.7 \times 10^{-6}t}) - 2.35$$

for complete depletion $X_\ell = 0$ and $X_{\ell_0} = 64 \times 10^{-6}$

so $$e^{-1.7 \times 10^{-6}t} = \frac{2.35}{2.35 + 64 \times 10^{-6}} = 0.99997$$

$$-1.7 \times 10^{-6}t = -0.0000272337$$

$$t = 16 \text{ hours}$$

Lastly, let's look at the concentration two feet above the gas-liquid interface initially (this will drop off to zero at 16 hours).

The concentration profile above the liquid is:

$$-\frac{dy_A}{dx} = 1.06 \times 10^{-6}$$

initially at the gas liquid interface we have $Y_A = 0.05\ (64 \times 10^{-6})$ (where $X = 0$)

$$Y_A = 3.2 \times 10^{-6} = 3.2 \text{ ppm}$$

so $$\frac{3.2 - Y_{2ft}}{2ft} = 1.06$$

$$Y_{2ft} = 1.08 \text{ ppm}$$

Any effort to speed up the oxidation process such as low ph should enable the maintenance of low concentration above the tank. Forced convection would also do the job.

E. Recommendations

1. Determine the holding tank inlet pressure during a vent
2. Measure MMH in the tank and in the vapor space above the tank during a vent with current system
3. Do 1 and 2 after sparger is installed
4. Consider agitation if bubble coalescence occurs
5. Determine treatment schedule and/or second stage process to meet EPA standards for atmospheric MMH

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NASA JSC WSTF
TEST PREPARATION SHEET
CONTINUATION SHEET

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TPS NO. 4 - OTM- 763
MOD NO.

ITEM NO.	DESCRIPTION CONTINUED	WORKED SHOP	INSPECTED NASA
4	Announce Fuel Vapors Tube Vented To Pond		
5	Cycle DF32 open for 10 seconds. Record Pressures below. Repeat cycles until ACU is approx 40 PSIG	3/2/83	

SEC	PSIA FADF62P	PSIG DF60	Sec	A 62P	G 60
START	298	297	150	68	59
10	262	260	160	62	54
20	231	227	170	57	49
30	207	202	180	53	44
40	187	182			
50	167	162			
60	152	145			
70	140	135			
80	129	120			
90	118	112			
100	106	100			
110	98	85			
120	89	80			
130	81	75			
140	75	67			

1200 Gal. on board

6 fully decrease DF110, close DF111, and open DF02

CF 2-28-83
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JSC Form 1305A (Rev Feb 78)

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Hole-area distribution for liquid spargers

This TI-59 program does the tedious calculations involved in designing spargers, and prints (or displays) the results.

William H. Mink, Battelle Columbus Laboratories **

☐ In many operations, it is necessary to sparge a liquid or gas into another fluid; frequently, a uniform distribution is desired. Since, owing to frictional losses, the pressure decreases as the fluid flows down the sparger pipe, the hole area must increase along the length of the sparger to maintain uniform flow from it.

H.W. Cooper[†] has developed a series of relationships that are useful in calculating sparger hole area for uniform distribution. It has been pointed out that these equations are in error because the originator neglected to include the effect of velocity head. This velocity-head effect can be significant. Only when the pipe L/D ratio is high or when flowrates are low do the Cooper equations provide an approximation. The author has developed a new program, based on a stepwise calculation, which yields correct hole sizes regardless of L/D ratio or flowrates.

Calculational approach

The pressure causing flow through any orifice is the difference between the static pressure at the point of the orifice and the ambient pressure. The static pressure is the total pressure less the velocity head and any frictional loss:

$$P_s = P_t - P_{vh} - P_f \qquad (1)$$

For the sparger, the total inlet pressure is:

$$P_{t,in} = P_{s,in} + P_{vh,in} \qquad (2)$$

In Eq. (1) and (2),

$$P_{vh} = \frac{V^2\rho}{2g(144)} = \frac{V^2\rho}{9{,}274} \qquad (3)$$

$$V = \frac{0.4085Q}{d^2} \qquad (4)$$

and

$$P_f = \frac{FV^2\rho L/10}{d(193)} \qquad (5)$$

The friction factor, F, depends on the Reynolds number, N_{Re}:

$$F = 16/N_{Re}, \text{ if } N_{Re} < 2{,}100 \qquad (6)$$

$$F = 0.0035 + 0.264(N_{Re})^{-0.42}, \text{ if } N_{Re} \geq 2{,}100 \qquad (7)$$

where

$$N_{Re} = \frac{124\,\bar{V}d\rho}{\mu} \qquad (8)$$

The orifice area can be calculated by the orifice equation, which can be simplified to:

$$a = Q/1830[(P_s - P_a)/\rho]^{1/2} \qquad (9)$$

A program has been developed for the TI-59/PC-100A, using the above procedure. The program calculates the hole area for each 10% of sparger length (using Eq. (9)).

The program is shown in Table I. Certain constants for the calculations and for the alphanumeric operations must be stored in the data registers. These are shown in Table II. Once the calculator has been programed and the constants stored, both the program and data register contents may be recorded on magnetic cards for future use.

User instructions for calculation of the sparger hole areas that will achieve uniform flow distribution are given in Table III.

When running this program, the printer first prints out the entered data. Next, it prints the hole area for each 10% of sparger length, and finally it prints the total sparger hole area.

Procedure

For the calculation of the hole area in the first section (first 10% of length), the flowrate down the pipe is set at the entered value. For each subsequent hole-area calcu-

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**For information about the author see p. 228

[†] Cooper, Herbert W., Area Allocation for Distributor Pipes, Chem. Eng., Oct

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Program for use in calculating hole area of liquid spargers

Table I

Location	Code	Key	Location	Code	Key	Location	Code	Key	Location	Code	Key	Location	Code	Key	Location	Code	Key
000	76	LBL	060	69	OP	120	69	OP	180	04	4	240	03	3	300	73	RC*
001	11	A	061	05	05	121	00	00	181	95	=	241	00	0	301	09	09
002	42	STO	062	98	ADV	122	98	ADV	182	42	STO	242	95	=	302	69	OP
003	01	01	063	98	ADV	123	98	ADV	183	14	14	243	42	STO	303	04	04
004	25	CLR	064	43	RCL	124	43	RCL	184	02	2	244	17	17	304	43	RCL
005	91	R/S	065	21	21	125	19	19	185	01	1	245	87	IFF	305	10	10
006	76	LBL	066	69	OP	126	69	OP	186	00	0	246	01	01	306	44	SUM
007	12	B	067	04	04	127	01	01	187	00	0	247	89	π	307	08	08
008	42	STO	068	43	RCL	128	43	RCL	188	32	X:T	248	76	LBL	308	58	FIX
009	02	02	069	01	01	129	20	20	189	43	RCL	249	77	GE	309	03	03
010	25	CLR	070	69	OP	130	69	OP	190	13	13	250	29	CP	310	69	OP
011	91	R/S	071	06	06	131	02	02	191	65	×	251	43	RCL	311	06	06
012	76	LBL	072	43	RCL	132	06	6	192	01	1	252	18	18	312	58	FIX
013	13	C	073	22	22	133	01	1	193	02	2	253	75	-	313	09	09
014	42	STO	074	69	OP	134	69	OP	194	04	4	254	43	RCL	314	01	1
015	03	03	075	04	04	135	04	04	195	65	×	255	17	17	315	44	SUM
016	25	CLR	076	43	RCL	136	69	OP	196	43	RCL	256	95	=	316	09	09
017	91	R/S	077	02	02	137	05	05	197	04	04	257	42	STO	317	61	GTO
018	76	LBL	078	69	OP	138	03	3	198	65	×	258	18	18	318	69	OP
019	14	D	079	06	06	139	04	4	199	43	RCL	259	75	-	319	76	LBL
020	42	STO	080	43	RCL	140	42	STO	200	06	06	260	43	RCL	320	68	NOP
021	04	04	081	23	23	141	09	09	201	55	÷	261	14	14	321	98	ADV
022	25	CLR	082	69	OP	142	86	STF	202	43	RCL	262	75	-	322	43	RCL
023	91	R/S	083	04	04	143	01	01	203	05	05	263	43	RCL	323	30	30
024	76	LBL	084	43	RCL	144	98	ADV	204	85	+	264	03	03	324	69	OP
025	16	A'	085	03	03	145	43	RCL	205	01	1	265	95	=	325	01	01
026	42	STO	086	69	OP	146	01	01	206	95	=	266	22	INV	326	43	RCL
027	05	05	087	06	06	147	42	STO	207	42	STO	267	77	GE	327	31	31
028	25	CLR	088	43	RCL	148	11	11	208	15	15	268	38	SIN	328	69	OP
029	91	R/S	089	24	24	149	01	1	209	77	GE	269	34	√X	329	02	02
030	76	LBL	090	69	OP	150	42	STO	210	87	IFF	270	35	1/X	330	43	RCL
031	17	B'	091	04	04	151	12	12	211	01	1	271	65	×	331	32	32
032	42	STO	092	43	RCL	152	00	0	212	06	6	272	43	RCL	332	69	OP
033	06	06	093	04	04	153	42	STO	213	55	÷	273	01	01	333	03	03
034	25	CLR	094	69	OP	154	08	08	214	43	RCL	274	[illegible]		334	43	RCL
35	91	R/S	095	06	06	155	76	LBL	215	15	15	275	43	RCL	335	33	33
036	76	LBL	096	43	RCL	156	69	OP	216	95	=	276	06	06	336	69	OP
037	18	C'	097	25	25	157	43	RCL	217	42	STO	277	34	√X	337	04	04
038	42	STO	098	69	OP	158	11	11	218	16	16	278	55	÷	338	69	OP
039	07	07	099	04	04	159	55	÷	219	25	CLR	279	01	1	339	05	05
040	25	CLR	100	43	RCL	160	43	RCL	220	76	LBL	280	08	8	340	98	ADV
41	91	R/S	101	05	05	161	04	04	221	88	DMS	281	03	3	341	25	CLR
042	76	LBL	102	69	OP	162	33	X^2	222	43	RCL	282	00	0	342	43	RCL
043	15	E	103	06	06	163	65	×	223	16	16	283	95	=	343	08	08
044	98	ADV	104	43	RCL	164	93	.	224	65	×	284	42	STO	344	58	FIX
045	29	CP	105	26	26	165	04	4	225	43	RCL	285	10	10	345	03	03
46	69	OP	106	69	OP	166	00	0	226	13	13	286	43	RCL	346	99	PRT
047	00	00	107	04	04	167	08	8	227	33	X^2	287	11	11	347	58	FIX
48	43	RCL	108	43	RCL	168	05	5	228	65	×	288	75	-	348	09	09
49	27	27	109	06	06	169	95	=	229	43	RCL	289	43	RCL	349	76	LBL
50	69	OP	110	69	OP	170	42	STO	230	06	06	290	01	01	350	30	TAN
51	02	02	111	06	06	171	13	13	231	65	×	291	55	-	351	98	ADV
52	43	RCL	112	02	2	172	33	X^2	232	43	RCL	292	01	1	352	98	ADV
53	28	28	113	07	7	173	65	×	233	07	07	293	00	0	353	98	ADV
54	69	OP	114	69	OP	174	43	RCL	234	55	÷	294	95	=	354	98	ADV
55	03	03	115	04	04	175	06	06	235	43	RCL	295	22	INV	355	91	R/S
56	43	RCL	116	43	RCL	176	55	-	236	04	04	296	77	GE	356	76	LBL
57	29	29	117	07	07	177	09	9	237	55	-	297	68	NOP	357	38	SIN
58	69	OP	118	69	OP	178	02	2	238	01	1	298	42	STO	358	98	ADV
59	04	04	119	06	06	179	07	7	239	09	9	299	11	11	359	69	OP

Location	Code	Key	Location	Code	Key	Location	Code	Key	Location	Code	Key	Location	Code	Key
360	00	00	375	69	OP	390	76	LBL	405	22	INV	420	93	.
361	43	RCL	376	00	00	391	89	π	406	86	STF	421	02	2
362	44	44	377	43	RCL	392	43	RCL	407	01	01	422	06	6
363	69	OP	378	47	47	393	02	02	408	61	GTO	423	04	4
364	01	01	379	69	OP	394	85	+	409	77	GE	424	85	+
365	43	RCL	380	03	03	395	43	RCL	410	76	LBL	425	93	.
366	45	45	381	43	RCL	396	14	14	411	87	IFF	426	00	0
367	69	OP	382	48	48	397	85	+	412	43	RCL	427	00	0
368	02	02	383	69	OP	398	43	RCL	413	15	15	428	03	3
369	43	RCL	384	04	04	399	17	17	414	45	Y^X	429	05	5
370	46	46	385	69	OP	400	55	÷	415	93	.	430	95	=
371	69	OP	386	05	05	401	02	2	416	04	4	431	42	STO
372	03	03	387	25	CLR	402	95	=	417	02	2	432	16	16
373	69	OP	388	61	GTO	403	42	STO	418	94	+/-	433	61	GTO
374	05	05	389	30	TAN	404	18	18	419	65	×	434	88	DMS

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Data register contents **Table II**

Register contents	Register		
0	00	Not used	
0.	01	g·m	Data entered by user-defined keys
0.	02	P_m	
0.	03	P_e	
0.	04	d	
0.	05	μ	
0.	06	ρ	
0.	07	L	
0.	08	Σ_e	Calculated by program
0.	09	W_m	
0.	10	σ	
0.	11	ϵ	
0.	12	W	
0.	13	N_{Re}	
0.	14	P_s	
0.	15	s	
0.	16	Not used	
0.	17	Index	
0.	18	n	
243170.	19		Alphanumeric code
6302016127.	20		
223330.	21		
33752431.	22		
33751330.	23		
2416.	24		
42243615.	25		
161731.	26		
2724344124.	27		
1600363313.	28		
3522173500.	29		

Register contents	Register	
[illegible]1327.	30	Alphanumeric code
[illegible]22717.	31	
[illegible]3351713.	32	
[illegible]0243170.	33	
1630201.	34	
630301.	35	
630401.	36	
630501.	37	
630601.	38	
630701.	39	
631001.	40	
631101.	41	
631201.	42	
63020101.	43	
361727.	44	
1715370027.	45	
1335221735.	46	
3375243100.	47	
3235002416.	48	

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User instructions for running program — Table III

Step	Procedure	Enter	Press	Display/print
1	Enter program (use standard partitioning)			
2	Enter data	Flow to sparger, gpm	A	GPM
		Pressure to sparger, psia	B	PAIN
		Ambient pressure, psia	C	PAAM
		Sparger I.D., in.	D	ID
		Sparger fluid viscosity, cP	A'	VISC
		Sparger fluid density, lb/ft^3	B'	DEN
		Sparger length, ft	C'	L
3	Calculate		E	Hole area per 10% of sparger length, and total hole area, in.^{2}
			R/S*	Hole area per 10% of sparger length, and total hole area, in.^{2}

*Required only if program is altered for use without printer (see text).

lation, the flowrate down the pipe is reduced by 10% of the entered value.

The velocity is calculated by Eq. (4) (Step 157 in the program shown in Table I), the velocity head by Eq. (3) (Step 172), and the Reynolds number by Eq. (8) (Step 189).* The appropriate equation for friction factor is selected [Eq. (6) or (7)]. The frictional loss is calculated by Eq. (5) (Step 222).

The pressure difference, $P_s - P_e$, is calculated using Eq. (1) and the entered ambient pressure. This difference is then used to calculate the area, using Eq. (9). This series of calculations starts at Step 251.

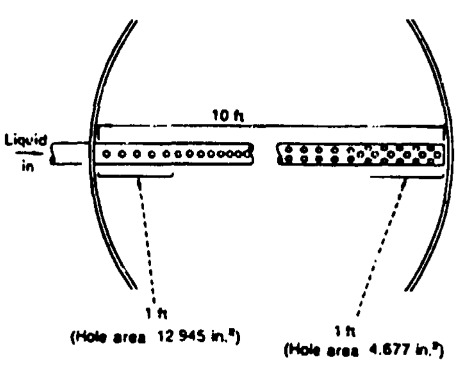
It should be noted that, since the entered P_{in} is a static pressure, $P_{t,in}$ must be calculated using Eq (2). (Since holes are assumed to be located at the center of each section, the frictional loss for the first section takes place over only 5% of the pipe length rather than 10% as for the subsequent sections. To adjust for the program, which subtracts the frictional loss for 10% of the pipe length for each hole calculation, the initial total pressure used in the calculation is increased by one-half of the initial frictional loss.)

Sample problem

Cooper demonstrated the calculation of hole area with the following example:

Consider 2,000 gal/min of water at 25 psia and 95°F, which is to be sprayed onto a distributor plate via holes in an internal pipe that is 10 ft long. Determine the area allocation for a 6-in. pipe. Tower pressure is 24.5 psia. In this case, $\rho = 62.4$ lb/cu ft, $\mu = 0.76$ cP.

Table IV shows the printout for this example. The areas calculated differ substantially from those calculated by Cooper; in this example, velocity head is an important factor.



Liquid sparger design of sample problem — Fig. 1

Fig. 1 shows, diagramatically, the application of the calculated results. (The hole size and spacing shown are for illustrative purposes and do not relate to the sample problem.) In this example, the hole area could be obtained by several combinations of hole sizes and numbers of holes. One possible arrangement would be to have 16 1-in. holes over the first 10% of length, 11 1-in holes over the next 10% of length, and finally 6 1-in holes over the last 10% of length.

If the TI-59 is to be used without the printer, it will be necessary to make one change in the program, as follows:

1. Enter the program as shown in Table I

---

*The Reynolds number is increased by 1 in the program so that Eq. (5) does not give an infinite result (causing the calculator to indicate an error condition at the end of the calculation) when V = 0. The addition of 1 has negligible effect on the calculation results.

Sample calculation **Table IV**

```
          LIQUID SPARGER

            2000.       GPM
              25.       P.IN
             24.5       P.AM
           6.0648         ID
             0.76       VISC
             32.4        DEN
              10.          L

        IN²/10%L           %

           12.945       0/10
            9.697        /20
            7.101        /30
            6.230        /40
            5.680        /50
            5.307        /60
            5.047        /70
            4.866        /80
            4.746        /90
            4.677       /100
     TOTAL HOLE AREA, IN²

           65.296
```

2. Make a program addition by pressing the following key sequence: GTO; 344; LRN; 2nd Del; 2nd Del; LRN; GTO; 312; LRN; 2nd Ins; R/S; LRN.

With this change, the calculator will display the hole area for the first 10% of sparger length after E is pressed. Repeatedly pressing R/S will cause the calculator to display the hole area for each of the next sparger segments in turn and, finally, the total hole area. As an aid to the operator, for identification purposes, the hole areas for the sparger segments are displayed in Fix 3 mode while the total hole area is displayed in Fix 9 mode.

Nomenclature

a	Orifice area, in.²
d	Sparger pipe I.D., in.
D	Sparger pipe I.D., ft
L	Pipe length, ft
P_a	Ambient pressure (pressure sparger is discharging into), psia
P_{in}	Initial (entered) static pressure, psia
P_f	Frictional loss, psi
P_s	Static pressure, psia
P_t	Total pressure, psia
P_{vh}	Velocity head, psi
Q	Flowrate entering sparger pipe, gpm
V	Velocity in sparger pipe, ft/s
ρ	Fluid density, lb/ft³
μ	Fluid viscosity, cP

Should the data entered result in an impossible solution (such as might occur if the sparger diameter were too small to permit the required flow at the specified pressures), the calculator will print out "SELECT LARGER PAIN OR ID."

For HP-67/97 users

The HP version of the program closely follows the TI version. Table V prvides a listing of the HP program, user instructions for the HP version are identical to those provided in Table III, with A', B', and C', replaced by a, b, and c, respectively.

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Program listing for HP version **Table V**

Step	Key	Code	Step	Key	Code	Step	Key	Code	Step	Key	Code	Step	Key	Code
001	*LBLA	21 11	021	R/S	51	041	PRTX	-14	061	×	-35	081	3	03
002	STO1	35 01	022	*LBLD	21 14	042	RCL6	36 06	062	√X	54	082	5	05
003	STO7	35 07	023	STO4	35 04	043	PRTX	-14	063	÷	-24	083	×	-35
004	CF1	16 22 01	024	R/S	51	044	SPC	16-11	064	STO9	35 09	084	STOB	35 12
005	R/S	51	025	*LBLc	21 16 13	045	F1?	16 23 01	065	RCL7	36 07	085	RCL5	36 05
006	*LBLa	21 16 11	026	STO5	35 05	046	GSB1	23 01	066	RCL5	36 05	086	X²	53
007	STO1	35 01	027	R/S	51	047	F0?	16 23 00	067	÷	-24	087	3	03
008	SF1	16 21 01	028	*LBLd	21 16 14	048	GSB2	23 02	068	RCL6	36 06	088	×	-35
009	R/S	51	029	STO6	35 06	049	RCL8	36 08	069	÷	-24	089	RCLA	36 11
010	*LBLB	21 12	030	R/S	51	050	.	-62	070	STOB	35 12	090	X²	53
011	STO2	35 02	031	*LBLE	21 15	051	3	03	071	.	-62	091	-	-45
012	STO8	35 08	032	RCL1	36 01	052	2	02	072	4	04	092	RCLB	36 12
013	CF0	16 22 00	033	PRTX	-14	053	5	05	073	1	01	093	X²	53
014	R/S	51	034	RCL2	36 02	054	5	05	074	×	-35	094	3	03
015	*LBLb	21 16 12	035	PRTX	-14	055	÷	-24	075	CHS	-22	095	×	-35
016	STO2	35 02	036	RCL3	36 03	056	RCL3	36 03	076	1	01	096	÷	-24
017	SF0	16 21 00	037	PRTX	-14	057	X²	53	077	+	-55	097	STOC	35 13
018	R/S	51	038	RCL4	36 04	058	÷	-24	078	STOA	35 11	098	RCLA	36 11
019	*LBLC	21 13	039	PRTX	-14	059	RCL4	36 04	079	RCLB	36 12	099	3	03
020	STO3	35 03	040	RCL5	36 05	060	RCL7	36 07	080	.	-62	100	Yˣ	31

Step	Key	Code	Step	Key	Code	Step	Key	Code	Step	Key	Code	Step	Key	Code
101	2	02	122	2	02	143	√X	54	164	2	02	185	6	06
102	×	-35	123	7	07	144	STOE	35 15	165	×	-35	186	0	00
103	RCLA	36 11	124	×	-35	145	+	-55	166	RCLB	36 12	187	6	06
104	1	01	125	÷	-24	146	1	01	167	3	03	188	×	-35
105	8	08	126	CHS	-22	147	ENT↑	-21	168	×	-35	189	STO7	35 07
106	×	-35	127	STOD	35 14	148	3	03	169	÷	-24	190	RTN	24
107	RCL9	36 09	128	RCLD	36 14	149	÷	-24	170	-	-45	191	*LBL2	21 02
108	X²	53	129	2	02	150	Yˣ	31	171	√X	54	192	RCL2	36 02
109	×	-35	130	÷	-24	151	RCLD	36 14	172	√X	54	193	RCL4	36 04
110	+	-55	131	CHS	-22	152	2	02	173	RCL3	36 03	194	×	-35
111	RCLB	36 12	132	RCLD	36 14	153	÷	-24	174	×	-35	195	6	06
112	RCL9	36 09	133	X²	53	154	CHS	-22	175	PRTX	-14	196	0	00
113	X²	53	134	4	04	155	RCLE	36 15	176	SPC	16-11	197	÷	-24
114	×	-35	135	÷	-24	156	-	-45	177	CF0	16 22 00	198	STO6	35 06
115	2	02	136	RCLC	36 13	157	1	01	178	CF1	16 22 01	199	RTN	24
116	7	07	137	3	03	158	ENT↑	-21	179	R/S	51	200	R/S	51
117	×	-35	138	Yˣ	31	159	3	03	180	*LBL1	21 01			
118	+	-55	139	2	02	160	÷	-24	181	RCL1	36 01			
119	RCLB	36 12	140	7	07	161	Yˣ	31	182	.	-62			
120	3	03	141	÷	-24	162	+	-55	183	0	00			
121	Yˣ	31	142	+	-55	163	RCLA	36 11	184	3	03			

ADDENDUM

SPARGER SYSTEM FOR MMH-HELIUM VENTS

On page 4 the Sparger program for an example vent condition was run giving a result of a = 0.72 in^2 (total Sparger area). It was decided to run the same program for the same conditions, except for the Sparger inlet pressure which was 100 psi previously and is now taken to be 21 psi (instead of a Δ P of 80 psi as in the previous case we now have a Δ P of 1 psi through the Sparger).

The results are the following:

Hole Area, in^2/10% of Sparger length, L	%L
.664	10
.605	20
.562	30
.529	40
.503	50
.484	60
.468	70
.457	80
.449	90
.444	100

Total Area = 5.166 in^2 = a

Again, since the program is for liquids we need to multiply these numbers by 1/4 to get the areas needed for a gas vent. Also, in this case the area required continuously decreases as we go down the Sparger to compensate for velocity head loss.

Using this result, if we now refer to page 5 we have the following two equations for the first 10% of Sparger:

1. $nd_o = 1.136$ (10% of flow for each 10% of Sparger length)

2. $\pi\left(\frac{d_o}{2}\right)^2 n = a = \frac{.664}{4} = .166 \text{ in}^2$

Therefore $\frac{\pi d_o}{4}(1.136) = .166$

and $d_o = .184$ inches

$n = 6.17$ holes

Table I shows the results for 10% increments in length down the Sparger.

TABLE I. HOLE SIZE AND NUMBER REQUIRED

Percent	n (no. of holes)	do, in
10	6.17	.184
20	6.80	.167
30	7.29	.156
40	7.75	.147
50	8.15	.139
60	8.47	.134
70	8.76	.130
80	8.97	.127
90	9.13	.124
100	9.23	.123

Note, that we need far fewer holes of a larger diameter than in the previous case.