GAS GENERATION BY CHEMICAL REACTION FOR PRESSURIZING LIQUID ROCKET PROPELLANTS

Thesis by

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SUMMARY

This report is devoted to presenting the results of an investigation directed toward the design of a chemical gas generation system for the Wac Corporal.(a) In this case the function of gas generation is to provide the necessary pressure to inject the propellants into the rocket motor.

The investigation indicates that gas can be generated in the main acid tank of the Wac by injection of a controlled amount of aniline to react with the acid. This aniline is injected at the bottom of the acid tank, and is supplied from a small pressure cell contained integrally with the injector and aniline flow regulator. Tests show that this system is able to regulate the flow of aniline into the acid tank to maintain a pressure on the propellants within ± 20 psi. of the desired value.

A proposed package unit for installation on the Wac Corporal is shown in Fig. 1. This unit contains all the parts necessary for the gas generation function, and its installed weight, including the aniline, is estimated to be eight lbs.

The importance of the installation of such a unit on the Wac is seen when it is realized that the total weight of the gas

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(a) The Wac Corporal is a sounding rocket of 590 lbs. gross weight using red fuming nitric acid and aniline as propellants. It was designed at the California Institute of Technology Jet Propulsion Laboratory.

generation system, including the acid used, will be approximately 25 lbs. This system will replace the 90 lb. air pressurization unit now being used to pressurize the propellants and it will represent a 65 lb. reduction in initial gross weight. Such a weight reduction will lead to greatly improved rocket performance.

This report does not attempt to determine the range of gross weights over which gas generation systems will prove superior to other methods of propellant pressurization. It is felt, however, that a definite upper and lower limit on missile gross weight does exist for which gas generation will be applicable.

INTRODUCTION

The preliminary work on chemical gas generation was carried out by Canright with his work on mobile gas generation (Cf. Ref. 1), and his further work on airborne pressurizing systems (Cf. Ref. 2).

On the basis of the results obtained in the above two investigations it was thought that gas generation systems could be successfully designed if suitable means could be found to control the gas generation reaction. However, in lieu of a broad design study of the airborne gas generation field it was decided to concentrate on devising as quickly as possible a RFNA and aniline system for the Wac Corporal.

To begin the investigation it was believed logical to work toward a type of installation shown in Fig. 2, utilizing gravity feed to provide the aniline injection pressure. (The aniline head in the Wac Corporal varies from a minimum of 0.4 psi. to a maximum of 5.0 psi. during its operation.) A system of this type would afford the greatest possible weight saving as the components of a gas generating system replacing the present air pressure tank would be a minimum.

The configuration shown in Fig. 2 represents the pressurizing reaction taking place in the main acid tank with the aniline supplied from the main aniline tank. The function of the regulator shown in the aniline feed line is to regulate the aniline flow to maintain the desired propellant pressure for the rocket motor.

The difference in weight between such a system and the standard air pressurizing system can be roughly estimated as follows:

Define $\Omega = \frac{pV}{W}$ units are $\frac{\frac{lbs}{in^2}\;ft^3}{lbs}$

$\Omega = \frac{p\dot{V}}{\dot{W}}$ units are $\frac{\frac{lbs}{in^2}\;\frac{ft^3}{sec}}{\frac{lbs}{sec}}$

where p = generated pressure in $\frac{lb}{in^2}$

V = volume of generated gas in ft^3 at the prevailing pressure and temperature.

$\dot{V}$ = volume rate of generated gas in $\frac{ft^3}{sec}$ at the prevailing pressure and temperature.

W = weight of aniline and acid used in lbs.

$\dot{W}$ = weight rate of aniline and acid used in $\frac{lbs}{sec}$.

As $\frac{pV}{W} = RT$, it is seen that the parameter Ω depends on the absolute temperature of the generated gas. Data available in Ref. 1 shows $\Omega = 148$ at ambient temperatures for a mixture ratio of acid to aniline of 3.08. At higher mixture ratios Ω was found to decrease, falling to 100 at a mixture ratio of six.

This investigation showed (Cf. Table 1) that an airborne pressurizing system would operate at temperatures higher than ambient and at mixture ratios greater than three. For these conditions, $\Omega = 100$ can be assumed to be a representative value.

Using this Ω and Wac Corporal operating data, the total weight of propellants consumed in the gas generating reaction can be computed.

$\dot{w} = \frac{p\dot{v}}{\Omega}$ where

$p = 400$ psi. = propellant tank pressure

$\dot{v} = 0.1 \frac{ft^3}{sec}$ = volume flow rate of propellants

$\dot{w} = \frac{(400)(0.1)}{100} = 0.4 \frac{lbs}{sec}$

$W = \dot{w}\, t_b$ where

$t_b = 45$ sec = burning time

$W = (0.4)(45) = 18.0$ lbs of acid and aniline

If the weight of the regulator in the gas generation system is 2 lbs., and the injector plus lines and fittings is 5 lbs., the total weight of the system is 25 lbs.

Since the present overall weight of the air pressurizing system on the Wac is 90 lbs., incorporation of gas generation would provide a weight saving of 65 lbs. This figure represents an 11% reduction in initial gross weight.

To see what this weight saving means in increased altitude, the following equation (Cf. Ref. 3) can be used to approximate the maximum altitude obtainable (drag neglected).

$$h = \left[-I_{sp} g \ln(1-\nu)\right]^2 + I_{sp} g t \left[1 + \frac{1}{\nu} \ln(1-\nu)\right]$$

where h = altitude in ft.

I_{sp} = specific impulse in secs.

g = acceleration of gravity

t = burning time in secs.

$$\nu = \frac{\text{weight of propellants}}{\text{gross weight}}$$

Consider first the Wac Corporal using air pressurization.

Then: $W_p = 365$ lbs, $W_o = 590$ lbs, $t = 45$ sec., $I_{sp} = 200$ secs.,

and $\nu = \frac{365}{390} = 0.619$

$$h = \left[-(200)(32.2)\ln(1-0.619)\right]^2 + (200)(32.2)(45)\left[1 + \frac{\ln(1-0.619)}{0.619}\right].$$

$$h = 385{,}000 - 162{,}000$$

$$h = 223{,}000 \text{ ft.}$$

Now consider the Wac Corporal but with a gas generation system installed. Then: $W_p = 365$, $W_o = 590 - 65 = 525$, and $\nu = \frac{365}{525} = 0.695$.

In this instance the maximum altitude is:

$$h = 391{,}000 \text{ ft}$$

These two caculations then show a theoretical increase of altitude of 75% for the Wac to be realized by the incorporation of a gas generation system into the present design.

PROCEDURE AND EQUIPMENT

It was initially desired to determine if the reaction of acid and aniline would proceed from the acid tank down the aniline feed line at a rate greater than the incoming flow of aniline.

To observe the reaction of an acid surface in contact with an aniline surface, a simple apparatus shown in Fig. 3 was used. The diameter of the glass tube containing the aniline was varied from 4 to $5\frac{1}{2}$ to 8 mm. The maximum rate of recession of the burning surface occurred when the aniline was contained in the 8 mm tube. The maximum rate was of the order of only 2 inches in 30 seconds because of the periodic nature of the reaction.

This characteristic allowed the acid and aniline to react where-on the generated gases expelled the acid from the aniline tube causing a delay in the reaction. The acid then flowed back on the aniline and the cycle was repeated. The period of the process was about one second.

Assuming gas generation is to be used on the Wac and the aniline is injected through an 8 mm tube, the rate of aniline flow is 25 inches per second. This rate was calculated assuming $\Omega = 100$, a tank pressure of 400 psi., a volume flow rate of propellants of 0.1 cubic feet per second, and a mixture ratio of the generating reagents of 6 to 1.

From the results of this observation it was concluded that no special consideration need be given to the problem of preventing a reaction in the aniline feed line. It was discovered later, however, to be desireable to keep all acid out of the aniline injection line to prevent mild detonations during the starting transient.

The basic equipment used in conducting the major investigation consisted of three stainless steel tanks, designed to yield at a pressure of 4480 psi., and arranged in a suitable geometric configuration to allow gas cross-over from each tank to the others, and to allow suitable means of exhausting. The tanks were mounted in a steel box constructed of $\frac{1}{2}$ inch plate, the box being closed on all sides but the back to permit access to the tanks.

Fig. 4 is a schematic diagram of the system as originally built; Fig. 5 is a sketch of one of the stainless steel tanks, and Figs. 6 and 7 are photographs of the apparatus.

Temperature data was taken at the points indicated in Fig. 4 and was recorded on a twelve - channel Brown Recorder. Visual temperature gauges were also mounted on the panel of the box, which indicated temperatures at the bottoms of tanks A, B, and C of Fig. 4.

The "Mity Mite" pressure regulator used in the majority of the runs is shown in Fig 8. The "Mity Mite" is a standard on - off type regulator and was so placed in the system (Cf. Fig. 4) that it controlled the flow of aniline in order to maintain a predetermined pressure in tank B.

The data taken in the course of the investigation is given in Table 1. For discussion purposes the experimentation may be divided into two phases. During the first phase, which included runs one through fourteen, experimentation was directed mainly toward finding a system which would generate gas smoothly and regulate in a satisfactory manner. A variety of equipment configurations were tested during the first fourteen runs.

An example of the procedure followed in a typical run of the first phase is: (Cf. Table 1, Run 4 and Fig. 9)

1. 1000 cc of acid were introduced into tank B.
2. 1000 cc of aniline were introduced into tank A.
3. Cross-over valve A-B was opened.
4. Cross-over valve B-C was closed.
5. The regulating pressure in the "Mity Mite" dome was set to 100 psi.
6. Valve A-1 was opened.
7. Valve A-2 was opened slightly allowing the aniline to flow into tank B.
8. Manual adjustment of A-2 was maintained to prevent excessive pressure build up in case of malfunctioning of the regulator.
9. When the pressure stabilized at 100 psi. in tanks A and B, the regulating pressure in the "Mity Mite" was increased to 200 psi.
10. The "Mity Mite" then opened, and the pressure in tanks A and B rose to 235 psi, and then dropped to 185 psi.
11. The reaction was not smooth and was accompanied by audible knocking. The run was stopped after one minute.

12. The remaining acid and aniline was measured and Ω calculated to be 84.

During the first phase no suitable equipment configurations or testing techniques were discovered which would permit satisfactory gas generation. However, the experience gained led to modifications of the apparatus and new testing procedures which resulted in sucessful gas generation during the second phase of experimentation. The equipment modifications and changes in testing procedure were:

1. Aniline was pressurized with nitrogen and injected under pressure into the acid.
2. A calibrated orifice was placed in the aniline line downstream of the "Mity Mite" regulator to limit the maximum flow rate of aniline to a predetermined value. This was done to prevent pressure surges accompaning injection of large masses of aniline.
3. Sub-surface injection of aniline was used because of more reasonable temperatures encountered than when using above surface injection. (Cf. Table 1, Run 13, for description of above - surface injection)

In addition to these changes in operating procedure, remotely operated quick-opening valves were installed in the gas exhaust and the aniline feed lines to promote safer operating conditions. These changes are shown in Fig. 10. At the same time the equipment was given a general overhaul to remedy the damage done by a detonation in run 14b. (Cf. Table 1.)

The orifices used in the second phase of the investigation were calibrated in the aniline feed line in order to take into account any pressure losses caused by fittings. In addition to this a qualitative calibration was made of exhaust gas volume flow rate versus valve X-B (Cf. Fig. 10) position. This information was used to obtain exhaust valve openings comparable to anticipated gas generation rates.

The second phase of the experimentation proceeded smoothly, the only further equipment modification being the change of the orifice plate from downstream of the pressure regulator to upstream, and the installation of a new injector. This injector (Cf. Fig. 11) was designed to eliminate the knocking during the starting transient by preventing the acid from entering the aniline feed line prior to initiating the aniline flow.

An example of the procedure followed in the second phase is outlined below for run 20: (Cf. Table 1 for data and Fig. 12 for configuration).

1. 395 cc of aniline were introduced into tank A.
2. 3940 cc of acid were introduced into tank B.
3. Tanks B and C were interconnected by opening valve B-C.
4. Tank A was pressurized to 450 psi.
5. The regulating pressure in the "Mity Mite" dome was set at 400 psi.

6. Valve X-B was closed.

7. Valve A-1 was opened.

8. Valve A-2 was opened and the reaction started.

9. In 20 seconds the pressure in tank B had risen smoothly to 400 psi. and stabilized.

10. Valve A-2 was closed at the end of 22 seconds and the run was terminated.

11. The acid and aniline was drained from tank A and B, and the amount consumed during the run was determined.

12. Ω was calculated to be 105.

In general the gas generation process functioned smoothly during all the runs of the second phase, both when generating gas in a closed volume and when exhausting the generated gas. Figs. 13 and 14 show some additional configuration tested in this phase.

Run 23 was of particular interest as rate of change of pressure $\left(\frac{dp}{dt}\right)$ indicators were installed at the top, center, and bottom of tank B, and at the top of tank C. (Cf. Table 1 for data and configuration).

These indicators are of the magneto - strictive type, operating on the principle of a reluctance change with an applied stress variation. (See appendix for discussion of $\frac{dp}{dt}$ indicator calibration) The $\frac{dp}{dt}$ record of run 23 indicated a negligible shock to the system during the starting transient. It also indicated a pressure fluction of ± 20 psi. at the top of tank B with a period of 0.15 seconds during the steady state gas generation at 400 psi. These pressure fluctuations were damped to nearly zero at the top of tank C and had a phase lag of $\frac{1}{6}$ of a period with respect to the tank B fluctuations. It was estimated that the volume flow rate of generated gas was 0.146 cubic feet per second, a rate greater than the 0.1 cubic feet per second required by the Wac Corporal.

As seen in Table 1., rather large quantities of acid were consumed during the gas generation process as compared to the amounts of aniline used, particularly in the final runs. It is thought that this excessive consumption may be caused by the vaporization of some of the acid.

To determine the amount of acid being vaporized, a short analysis was carried out based on the following assumptions:

1. The total energy released by the combustion of the aniline goes into evaporating and raising the temperature of the acid.
2. No heat transfer from the acid to the surrounding medium occurs.
3. c_p acid $= 0.6 \frac{\text{cal}}{\text{g.}^\circ\text{C}}$
4. Heat of vaporization of acid $= 1000 \frac{\text{cal}}{\text{g}}$ @ 300 psi. and 100°C.
5. Energy released by the combustion of aniline $= 811{,}700 \frac{\text{cal}}{\text{mol}}$ (b)

   $= 8700 \frac{\text{cal}}{\text{g.}}$

If the data for run 19 is considered,

Aniline burned = 50 cc

Pressure in B = 300 psi.

Acid in B = 2000 cc

(b) "Langes Handbook of Chemistry"

Bubble point of acid = 100°C @ 300 psi

Ambient temperature = 15°C

Calories to heat acid to b.p. = (2000)(1.55)(.6)(100-15)

= 158,000 cal.

Calories liberated by aniline = (8700)(1.02)(50)

= 444,000 cal.

Calories left to vaporize acid = 444,000-158,000

= 286,000 cal.

Grams of acid vaporized = $\frac{286,000}{1000}$ = 286 g.

cc acid vaporized = $\frac{286}{1.55}$ = 184.5 cc

% acid vaporized = $\frac{184.5}{2000}$ = 9%(c)

In run 19, 20% of the acid was consumed. It is seen that almost half of this acid may have been lost through vaporization.

A similar calculation may be carried out for the Wac Corporal which shows that a negligible percentage of acid will be lost through vaporization.

Initial volume acid = 2.72 cubic ft. (For the Wac)
= 77,000 cc

At any time, t,

$$V \text{ acid} = 77000 \left(1 - \frac{t}{45}\right) \text{ cc}^{(d)}$$

(c) The difference between the acid boiling point and dew point has been neglected in this calculation.

(d) The Wac Corporal burning time is 45 seconds.

From data of run 20,

$$\Omega \text{ aniline} = \frac{pv}{W \text{ aniline}} = \frac{(400)(0.38)}{0.1462}$$

$$= 1032 \quad \frac{\text{psi. ft}^3}{\text{lb.}}$$

For the Wac,

$$\dot{w} \text{ aniline} = \frac{pv}{\Omega \text{ aniline}} = \frac{(400)(0.1)}{1032} = .0388 \frac{\text{lb}}{\text{sec}}$$

$$\dot{w} \text{ aniline} = 17.25 \quad \frac{\text{g.}}{\text{sec}}$$

$$\frac{\text{heat imput}}{\text{sec}} = (8700)(17.25) \; 150{,}000 \; \frac{\text{cal.}}{\text{sec}}$$

To compute the time to reach boiling point,

$$\delta Q = mc_p dt$$

T = temp. °C

t = time in seconds

$$\delta Q = 150{,}000 \; dt \quad \text{cal.}$$

$$cp = 0.6 \quad \frac{\text{cal.}}{\text{g.}\,^\circ\text{C}}$$

$$m = 77{,}000 \left(1 - \frac{t}{45}\right)(1.55) \text{ g.}$$

$$150{,}000 \; dt = 77{,}000 \; \frac{(45 - t)}{45}(1.55)(0.6) \; dT$$

$$\frac{94.3}{45-t} dt = dT$$

ambient temp. = 15°C

bubble pt. temp. of acid = 105.5°C @ 400 psi

$$\int_0^t \frac{94.3}{45-t} dt = \int_{15}^{105.5} dT$$

$$t = 45 - e^{-0.96}$$

$t = 44.6$ seconds to reach bubble point of the acid.

This analysis shows that the loss of acid through vaporization will be negligible. It also shows that the final temperature in the acid tank will be little above 105.5°C which means that the tank can be constructed of aluminum.

CONCLUSIONS

On the basis of the results to date, several conclusions can be formulated as to the essential points to be observed in the design of a successful gas generation system:

1. The aniline to be used should be supplied from a small pressurized cell separate from the main aniline tank.
2. Control of the maximum flow rate of aniline should be maintained, as with an orifice, to allow a fairly steady flow of aniline rather than intermittent injection of large amounts.
3. With the aid of an orifice, an on-off type pressure regulator seems capable of controlling the reaction.
4. Subsurface injection of the aniline is preferable to top surface injection as lower gas temperatures are encountered.
5. The temperatures are sufficiently low to permit the use of aluminum tanks.
6. The amount of residue formed by the reaction does not appear to be severe enough to cause any malfunctioning of the gas generating apparatus or the rocket motor.

On the basis of the foregoing conclusions, it is believed that gas generation can be incorporated into current missiles with only slight modification. The gas generation system for the Wac Corporal (Fig. 1) consists of a "package unit" weighing 8 lbs, which screws into the bottom of the acid tank, and contains all the necessary parts for the pressure generation function. The unit consists of a 5 inch diameter sphere which contains a small amount of aniline under pressure a poppet type injector, a pressure regulator, a starting trigger, and also incorporates the acid outlet to the Wac motor. The sphere is of 65 cu. in. capacity, and contains 25 cu. in. of aniline, and nitrogen or air at 1000 psi. pressure.

RECOMENDATIONS

Work is being continued at the California Institute of Technology Jet Propulsion Laboratory on the gas generating problem with a Wac scale system under construction (Cf. Figs. 15, 16a, and 16b).

It is felt that with this equipment available the following points should be investigated:

1. Determine Ω more accurately.
2. Investigate temperatures attained during full-scale operation.
3. Note effect of the generated gases on the aniline.
4. Investigate pressure fluctuations in system at steady state operating condition by using $\frac{dp}{dt}$ indicators.
5. Study the effect of the reaction on rocket motor performance.
6. Determine practicability of package unit.

The authors feel that with the sucessful conclusion of the small scale gas generation study, that the further work on the full scale system will soon result in operational missiles pressurized with chemically generated gases.

APPENDIX

Considerable thought was given to the measurement of pressure fluctuations within the gas generating apparatus as it was believed that these fluctuations would be too rapid to be recorded by an ordinary barometric pressure gage.

In order to obtain a record of these fluctuations it was decided to use detonation pick ups in conjunction with a Miller Recorder. It was then necessary to devise a program to calibrate the pick ups which measured rate of change of pressure, i.e. $\frac{dp}{dt}$.

To do this it was decided to pressurize a 3.244 cubic ft. tank of water, and then allow the gas to expand and do work in forcing the water out through a quick opening valve installed in the bottom of the tank.

The detonation pick ups were mounted in the cap of the tank, and a $\frac{dp}{dt}$ versus time record was obtained on the Miller Recorder.

To record the water level as a function of time a resistance ladder was placed in the tank and the change in resistance as the water level passed each rung was recorded. The calibration apparatus is shown in figure 17.

In order to determine the order of magnitude of the $\frac{dp}{dt}$ range of this apparatus, an equation for $\frac{dp}{dt}$ was derived, based on the assumption that the gas expansion in the tank was isentropic.

The equation is:

$$\frac{dp}{dt} = -\sqrt{\frac{2}{\rho_w}} \cdot \frac{\gamma A C}{V_0 \, p_0^{\frac{1}{\gamma}}} \cdot p^{\frac{3\gamma+2}{2\gamma}}$$

Where: ρ_w = Density of water in $\frac{\text{slugs}}{\text{ft}^3}$

γ = 1.404

C = Discharge coefficient for the outlet valve

A = Area of valve opening is ft^2

V_o = Initial volume of gas in ft^3

p_o = Initial pressure of gas in $\frac{\text{lbs}}{\text{ft}^2}$

p = Final pressure of gas in $\frac{\text{lbs}}{\text{ft}^2}$

In this case C was assumed to be 0.6 and the area of the valve was 0.0145 ft^2.

Changing $\frac{dp}{dt}$ to $\frac{\text{lbs}}{\text{in}^2 \text{ sec}}$ for convience in calculations, we have:

$$\frac{dp}{dt} = -\frac{0.1489\, p^{2.213}}{V_o\, p_o^{0.713}}$$

where p = Pressure in $\frac{\text{lbs}}{\text{in}^2}$ at any instant

p_o = Initial pressure in $\frac{\text{lbs}}{\text{in}^2}$

V_o = Initial volume in ft^3

Selecting various values of p_o and V_o, curves of $\frac{dp}{dt}$ vs pressure were obtained. These curves are shown in figures 8 and 19.

With this information several runs were made selecting different initial pressures and volumes in order to obtain varied rates of pressure change.

The initial pressure was measured with a bourdon gauge, and since the final volume was known, the final pressure was computed using the assumption of an isentropic expansion.

The difference of the final and initial pressures gave Δp for the expansion, and this Δp was used to calibrate the detonation pick ups, since integrating the area under the $\frac{dp}{dt}$ versus time curves also gives Δp. Table 2 shows the results of this calibration.

The resistance ladder failed to record accurately and thus it was not possible to obtain a pressure-time curve which would have given a second method of calibrating the $\frac{dp}{dt}$ indicators.

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TABLE I

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RUN	CONFIGURATION	VALVING	INITIAL ANILINE CC	INITIAL ACID CC	P_A PSI	REGULATOR PRESSURE PSI	INJECTOR	EXHAUST VALVE OPENING	MAX. TEMP. IN TANK B, °F			P_B PSI	PRESS. FLUCT. PSI	TIME FOR RUN SEC.	ANILINE USED CC	ACID USED CC	$r = \frac{W_{ACID}}{W_{ANILINE}}$	$\Omega = \frac{PV}{W}$	$\Omega_{ANILINE} = \frac{PV}{W_{ANILINE}}$	RESIDUE	REMARKS
									TOP	CENTER	BOTTOM										
1	FIG. 13	B-C	200	1000	300	NO REG.	MANUAL, 7.4 CC PER SHOT	CLOSED	173	265	125	168	0	—	126	400	4.8	46.5	575	CONSIDERABLE CARBON PLUS YELLOW FLAKY MATERIAL	EXCESS RESIDUE BELIEVED CAUSED BY INJECTION OF ANILINE IN FINE SPRAY
2	FIG. 9	A-B-C	200	1000	100 150 200 250	50 100 150 200	TOP SURFACE FIG. 14a.	CLOSED	252	365	97	50 100 150 200	±5 ±5 ±8 ±5	—	127	100	1.2	138	572	SOFT, FLAKY CARBON IN BOTH TANKS	OPERATION OF REGULATOR WAS AUGMENTED BY MANUAL CONTROL OF A-2. NO TEMPERATURE RISE IN TANK A
3	SAME AS 2	A-B-A	200	1000	GRAVITY FEED	50 80 120 150 200	SUBSURFACE FIG. 14b.	X-B OPENED SLIGHTLY	—	—	—	50 80 120 150 200	+100	—	150	255	2.6	—	—	SLIGHT CARBON DEPOSIT IN BOTH TANKS	AUDIBLE KNOCKING, SOME PRESSURE SURGES. MANUAL CONTROL OF VALVE A-2 USED WITH REGULATOR
4	SAME AS 2	A-B-A	1000	1000	GRAVITY FEED	100 200	SAME AS 3	CLOSED	150	220	135	100 200	+35 -15	60	65	248	5.7	84	367	NO SOLID RESIDUE	MOST OF SOLID RESIDUE OF PREVIOUS RUNS FOUND TO BE CAUSED BY FLUSHING SYSTEM WITH WATER
5	SAME AS 2	A-B-A	1000	2000	GRAVITY FEED	100 200	SAME AS 3	X-B OPENED 120°	230	300	140	100 200	±40 +100	—	133	775	8.8	—	—	SLIGHT DEPOSIT	VERY ERRATIC REGULATION
6	INSTALLED ½" LINE FROM STRAINER TO BOTTOM OF B. DRILLED INLET & OUTLET HOLES IN MITY MITE FROM 0.187 TO 0.249. DRILLED HOLE IN B TO 0.312. INSTALLED GROVE REGULATOR. FIG. 9	A-B-A	1000	2000	GRAVITY FEED	100 200	SUBSURFACE FIG. 14c.	X-B OPENED SLIGHTLY AFTER REGULATED PRESS. WAS REACHED	250	260	160	100 200	±50 +200 -50	—	—	—	—	—	—	VERY SLIGHT CARBON FORMATION	PRESSURE FLUCTUATIONS ALMOST DETONATIONS. REGULATION EXTREMELY ERRATIC
7	SAME AS 6	A-B-A	1000	2000	GRAVITY FEED	50 100 150 200	SAME AS 6	X-A OPENED AS PRESS. APPROACHED 200 PSI	—	—	—	50 100 150 200	+15 -50 +200	—	—	—	—	—	—	SLIGHT DEPOSIT	DETONATION AT 200 PSI
8	SAME AS 6	A-B-A	1000	2000	GRAVITY FEED	100	TOP SURFACE FIG. 14D.	X-A OPENED 120°	240	360	102	100	+40	—	—	—	—	—	—	SLIGHT DEPOSIT	FLUCTUATIONS HAD REGULAR PERIOD
9	SAME AS 6	A-B-A	1000	2000	GRAVITY FEED	100 200	TOP SURFACE FIG. 14E.	X-A OPENED TO VARIOUS POSITIONS	235	367	104	100 200	±20 +80 -50	—	—	—	—	—	—	NO SLUDGE IN ANILINE TANK	SOMEWHAT SMOOTHER OPERATION THAN PREVIOUS RUNS
10	SAME AS 6, NO REGULATOR	B-C	1000	2000	200	NO REGULATOR	SUBSURFACE SAME AS 3	X-B ADJUSTED TO MAINTAIN 100 PSI IN B	—	—	—	100	±50	—	—	—	—	—	—	SLIGHT	PRESSURE REGULATED WITH A-2

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TABLE I (CONTINUED)

RUN	CONFIGURATION	VALVING	INITIAL ANILINE CC	INITIAL ACID CC	P_A PSI	REGULATOR PRESS. PSI	INJECTOR	EXHAUST VALVE OPENING	MAX. TEMPS IN TANK B °F			P_B PSI	PRESS. FLUCT. PSI	TIME FOR RUN	ANILINE USED CC	ACID USED CC	$r = \frac{W\ ACID}{W\ ANILINE}$	$\Omega = \frac{PV}{W}$	$\Omega\ ANILINE = \frac{PV}{W\ ANILINE}$	RESIDUE	REMARKS
									TOP	CENTER	BOTTOM										
11	SAME AS 10	A-B-A	1000	2300	14.7	NO REGULATOR	SUBSURFACE NO STANDPIPE	X-B OPEN TO MAINTAIN DESIRED PRESS.	365	310	235	100 200	+100	—	—	—	—	—	—	SLIGHT	PRESSURE REGULATED WITH A-2. HARD TO START REACTION SMOOTHLY WITH GRAVITY FEED.
12	SAME AS 10	A-B-A	1000	2300	200	NO REGULATOR	SAME AS 11	X-B CLOSED				200 INITALLY	—	—	—	—	—	—	—	SLIGHT	STARTING CONDITION STILL POOR WITH BOTH TANKS INITIALLY PRESSURIZED & USING GRAVITY FEED.
13	SAME AS 10	A-B-A	1000	2300	14.7	NO REGULATOR	6 WAY OUTLET 6" ABOVE SURFACE FIG. 14 F	X-B OPEN TO MAINTAIN DESIRED PRESSURE	—	660°F	—	100 200	+50 +40	30 20	—	—	—	—	—	SLIGHT	SOME SURGES. HIGH TEMPERATURES IN TANK B
14A	MITY MITEREGULATOR IN ANILINE LINE. FIG. 9	A-B-A	1000	2300	200	100	SUBSURFACE FIG. 14 C	X-B OPEN 120°				100	±10	30	—	—	—	—	—	NOT CHECKED	
14B	SAME AS 14A	A-B-A	1000	2300	300	200	SAME AS RUN 14A	X-B OPEN 120°	TEMPERATURES IN EXCESS OF 1000 F.			100	+900	—	—	—	—	—	—	NOT CHECKED	DETONATION CAUSED SEVERE DAMAGE TO EQUIPMENT. BELIEVED CAUSED BY INJECTION OF EXCESSIVE ANILINE.
15	# 78 ORIFICE IN ANILINE LINE. FIG. 9	B-C	300	2000	200	100	SUBSURFACE FIG. 14G	X-B OPEN 360°	140	170	160	80	0	30	80	100		110		NOT CHECKED	SMOOTH OPERATION. X-B OPENED TOO FAR TO ALLOW P_B TO REACH 100 PSI
16	ORIFICE PLATE MOVED UPSTREAM OF REGULATOR #78 ORIFICE USED. FIG. 12	B-C	300	2000	300	100	SAME AS 15	X-B OPEN 360°	—	—	—	—	—	12	47	60		—	—	NOT CHECKED	RUN TERMINATED EARLY BECAUSE OF HARD KNOCK AT BEGINNING. TOP OF INJECTOR FOUND TO BE BLOWN OFF.
17	SAME AS 16	B-C	400	2000	200	100	FIG. 11, LOW VELOCITY PINTLE 2 f.P.S.	CLOSED	150	210	95	100	0	15	38	250	9.8	45	480	SLIGHT	SLIGHT KNOCK AT START OF RUN. SMOOTH PRESSURE BUILD UP
18	SAME AS 16	B-C	400	2000	300	190	SAME AS 17	CLOSED	150	186	120	190	0	15	36	275	11.5	86	1080	SLIGHT	SMOOTH PRESSURE BUILD UP
19	SAME AS 16	B-C	390	2000	340	300	SAME AS 17	CLOSED	225	205	168	300	0	15	50	480	14.5	76	1180	SLIGHT	SMOOTH PRESSURE BUILD UP
20	SAME AS 16	B-C	395	3940	450	400	SAME AS 17	CLOSED	224	222	158	400	0	22	65	350	8.1	105	960	SLIGHT	SMOOTH PRESSURE BUILD UP
21	SAME AS 16	B-C	400	3900	450	400	SAME AS 17 WITH NEW PINTLE FOR INJECTION VELOCITY OF 2 f.P.S.	CLOSED	216	212	145	400	0		60	468		88	1020	SLIGHT	NO INPROVEMENT IN SMOOTHNESS OF REACTION WITH HIGH VELOCITY INJECTION OF ANILINE.
22	SAME AS 16	B-C	380	4060	450	400	SAME AS 17 LOW VELOCITY PINTLE	X-B OPEN 360°	222	222	197	400	0	16	70	1240		ESTIMATED 61	ESTIMATED 1700	SLIGHT	CONSIDERABLE ACID LOST THROUGH VAPORIZATION. RUN SMOOTH.
23	SAME AS 16 WITH # 74 ORIFICE. DETONATION PICKUPS AT TOP, BOTTOM, & CENTER OF TANK B, & AT TOP OF TANK C	B-C	390	4000	470	400	SAME AS 17 FILLER BLOCK IN ANILINE CHAMBER	X-B OPEN 360°	218	218	202	400	20 PSI WITH 0.15 SEC. PERIOD	12	80	1314	25	ESTIMATED 85	ESTIMATED 2200	SLIGHT	CONSIDERABLE ACID LOST THROUGH VAPORIZATION. SEE DISCUSSION IN PROCEDURE.

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TABLE 2

Date	Run No.	$\frac{dp}{dt}$ No.	Area above base line	Area between base and 0 line	Area below curve	Δ p psi	$\frac{\Delta p}{in^2}$	t sec.	Galvonometer	Series resistance in $\frac{dp}{dt}$ circuit
2/18/47	3	418	6.11	5.33	0.78	381	488	2.03	40 cps	0 ohms
"	3	226	11.06	10.21	0.85	"	448	"	"	"
"	3	372	15.80	15.02	0.78	"	488	"	"	"
"	3	1747	26.38	26.10	0.28	"	1361	"	"	"
"	3	351	22.96	22.26	0.70	"	544	"	"	"
"	3	374	19.36	18.25	1.11	"	343	"	"	"
"	3	182	13.48	13.27	0.21	"	1814	"	"	"
2/18/47	4	418	6.20	5.34	0.86	464	540	2.04	40 cps	0 ohms
"	4	226	11.22	10.15	1.07	"	425	"	"	"
"	4	372	15.98	15.05	0.93	"	498	"	"	"
"	4	1747	26.63	26.16	0.47	"	989	"	"	"
"	4	351	23.32	22.31	1.01	"	458	"	"	"
"	4	374	19.86	18.29	1.57	"	296	"	"	"
"	4	182	13.64	13.30	0.34	"	1365	"	"	"
2/18/47	5	418	6.45	5.17	1.28	599	468	2.01	40 cps	0 ohms
"	5	226	11.48	10.00	1.48	"	405	"	"	"
"	5	372	16.07	14.65	1.42	"	352	"	"	"
"	5	1747	26.12	25.77	0.35	"	1710	"	"	"
"	5	351	23.20	22.07	1.13	"	442	"	"	"
"	5	374	19.98	18.10	1.88	"	266	"	"	"
"	5	182	13.40	13.10	0.30	"	1665	"	"	"
2/18/47	6	418	5.74	5.19	0.55	272	495	2.02	40 cps	0 ohms
"	6	226	10.64	10.03	0.61	"	446	"	"	"
"	6	372	15.26	14.70	0.56	"	484	"	"	"
"	6	1747	26.09	25.95	0.14	"	1942	"	"	"
"	6	351	22.65	22.14	0.51	"	532	"	"	"
"	6	374	18.98	18.16	0.82	"	332	"	"	"
"	6	182	13.38	13.15	0.23	"	1182	"	"	"

[redacted]

WAC GAS GENERATION UNIT

[redacted]

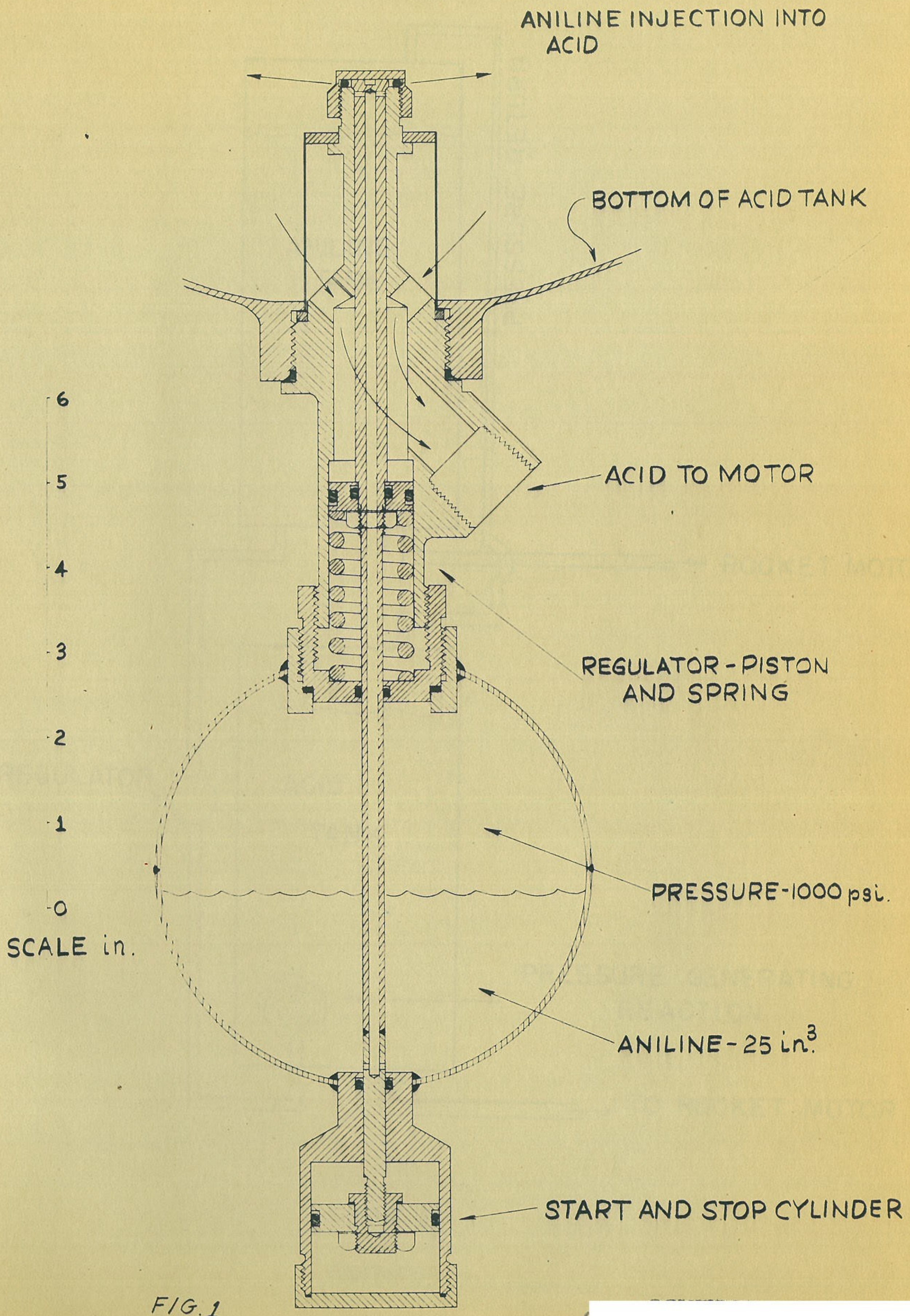

FIG. 1

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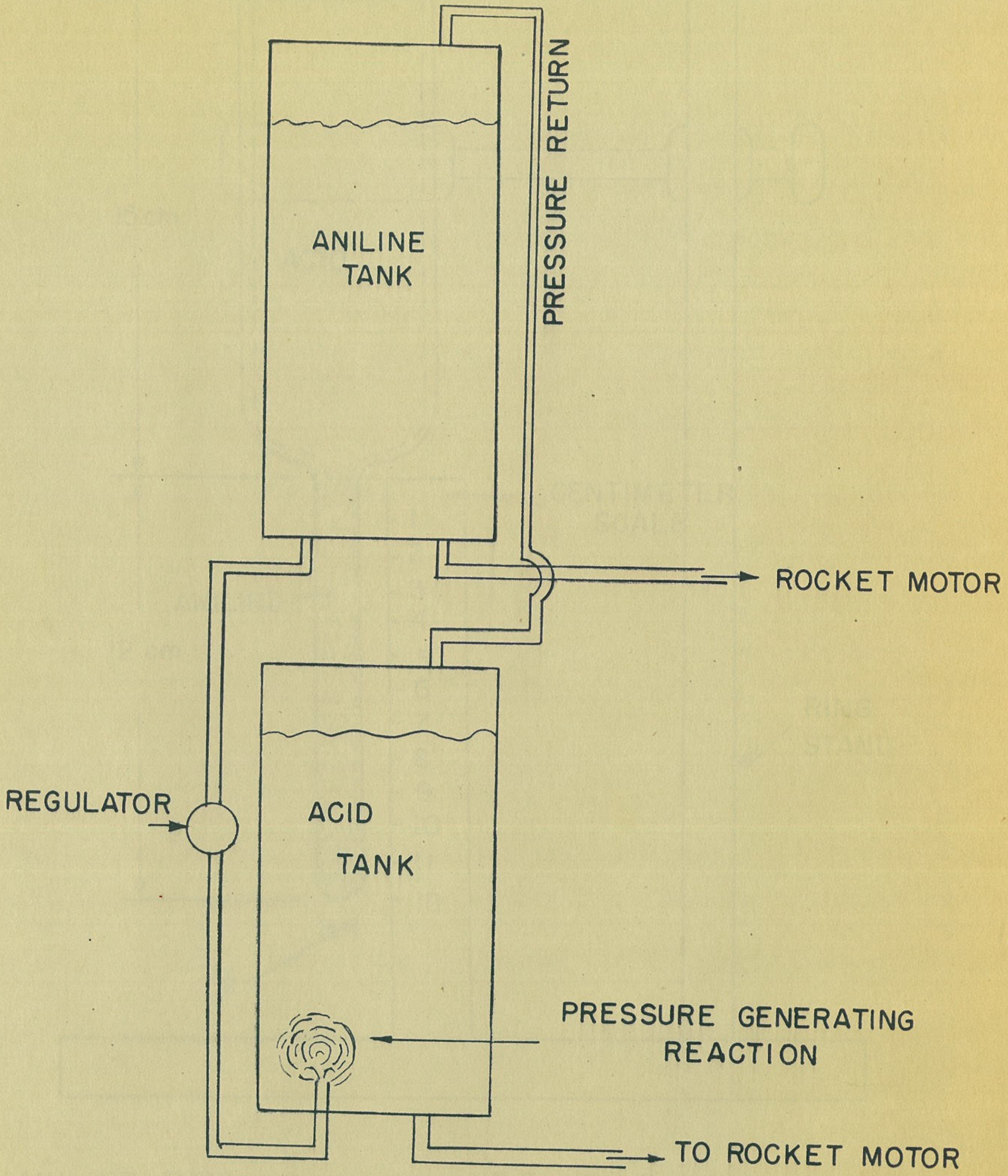
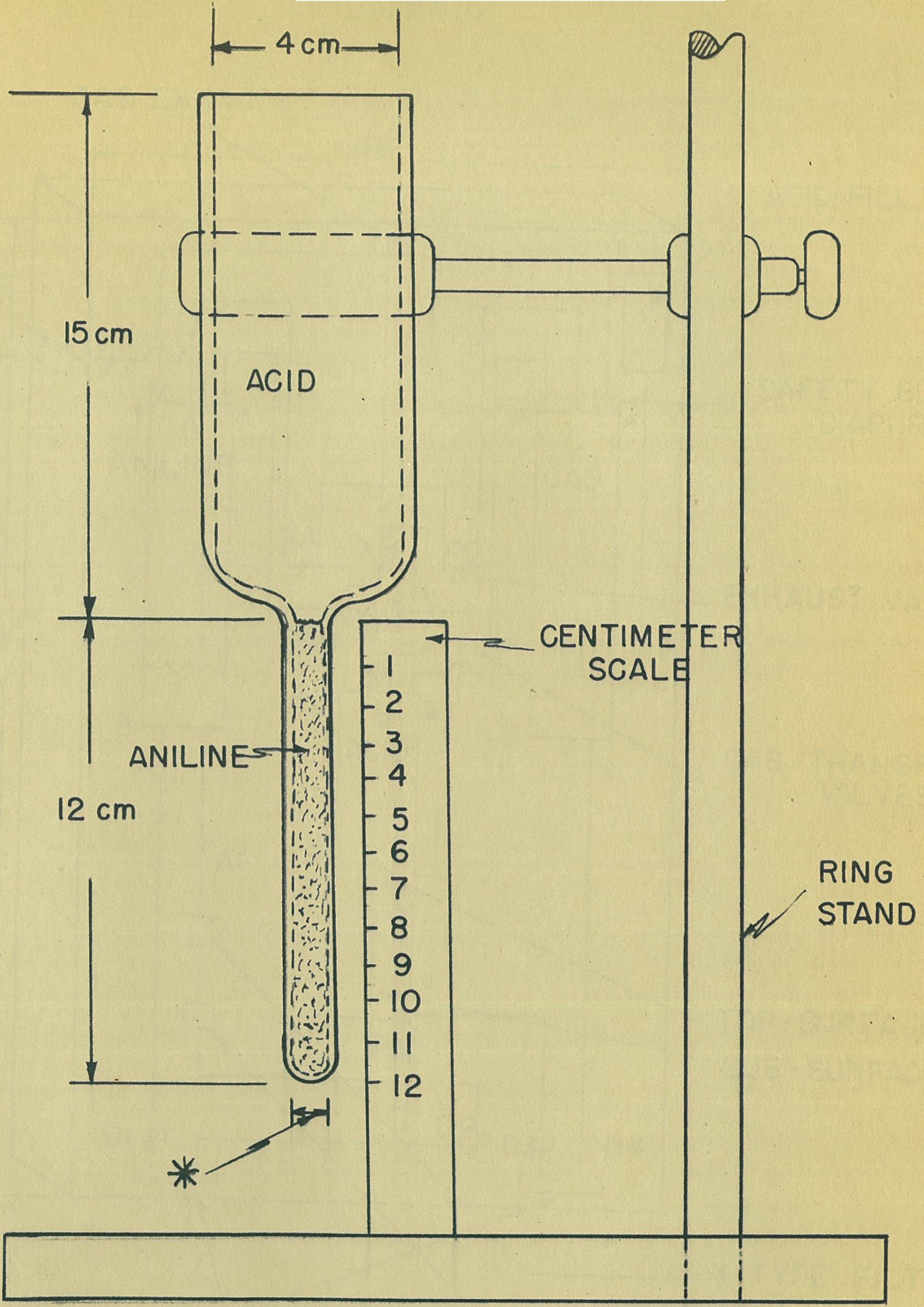


FIG. 2

[redacted]

[redacted]

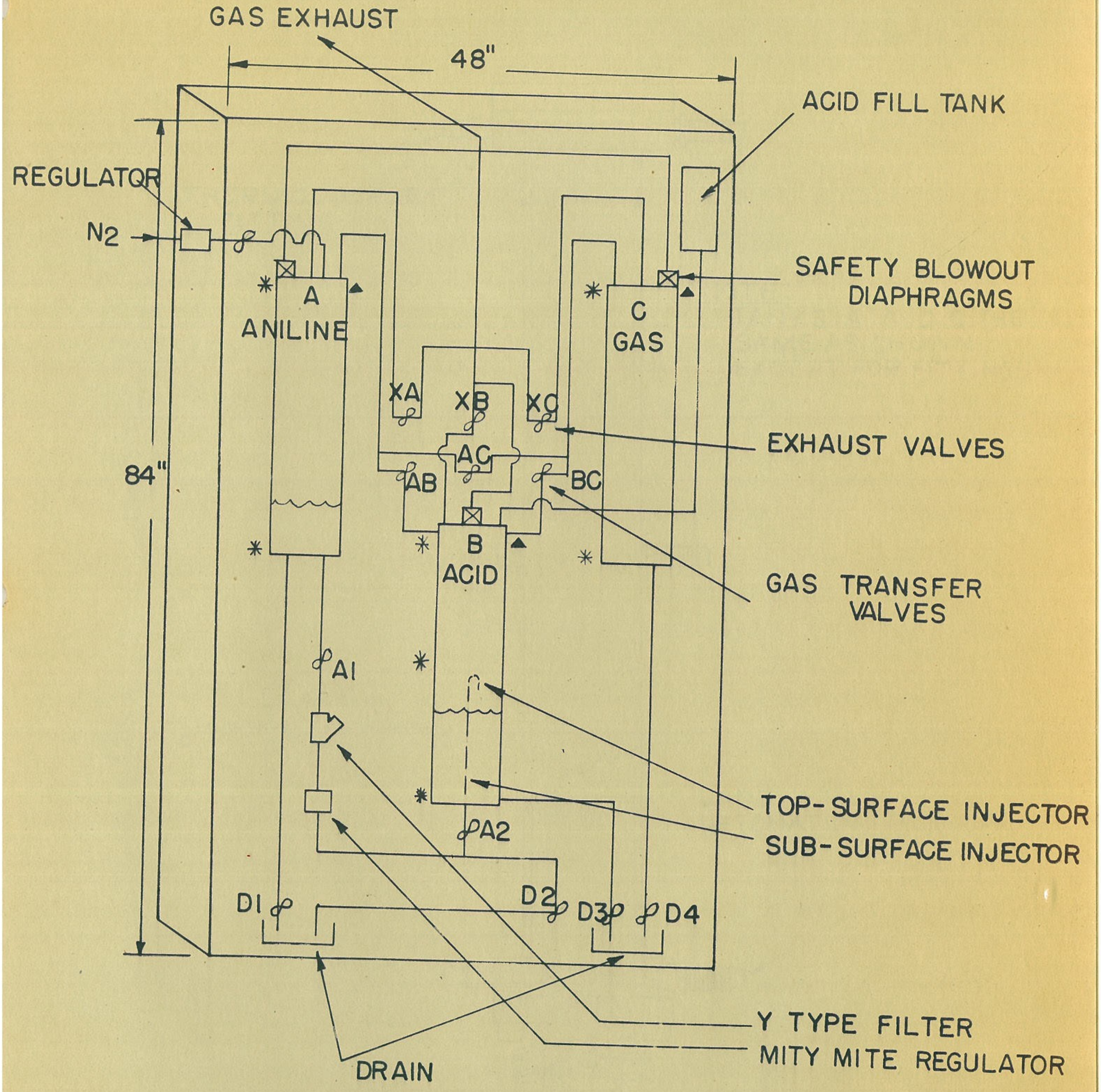


* ANILINE TUBE I.D. — 4 mm, 5.5 mm, 8 mm

FIG. 3

[redacted]

[redacted]



* THERMOCOUPLE POINTS

▲ PRESSURE TAPS

FIG. 4

[redacted]

[redacted]

COMBUSTION TANK "B" ASSEMBLY

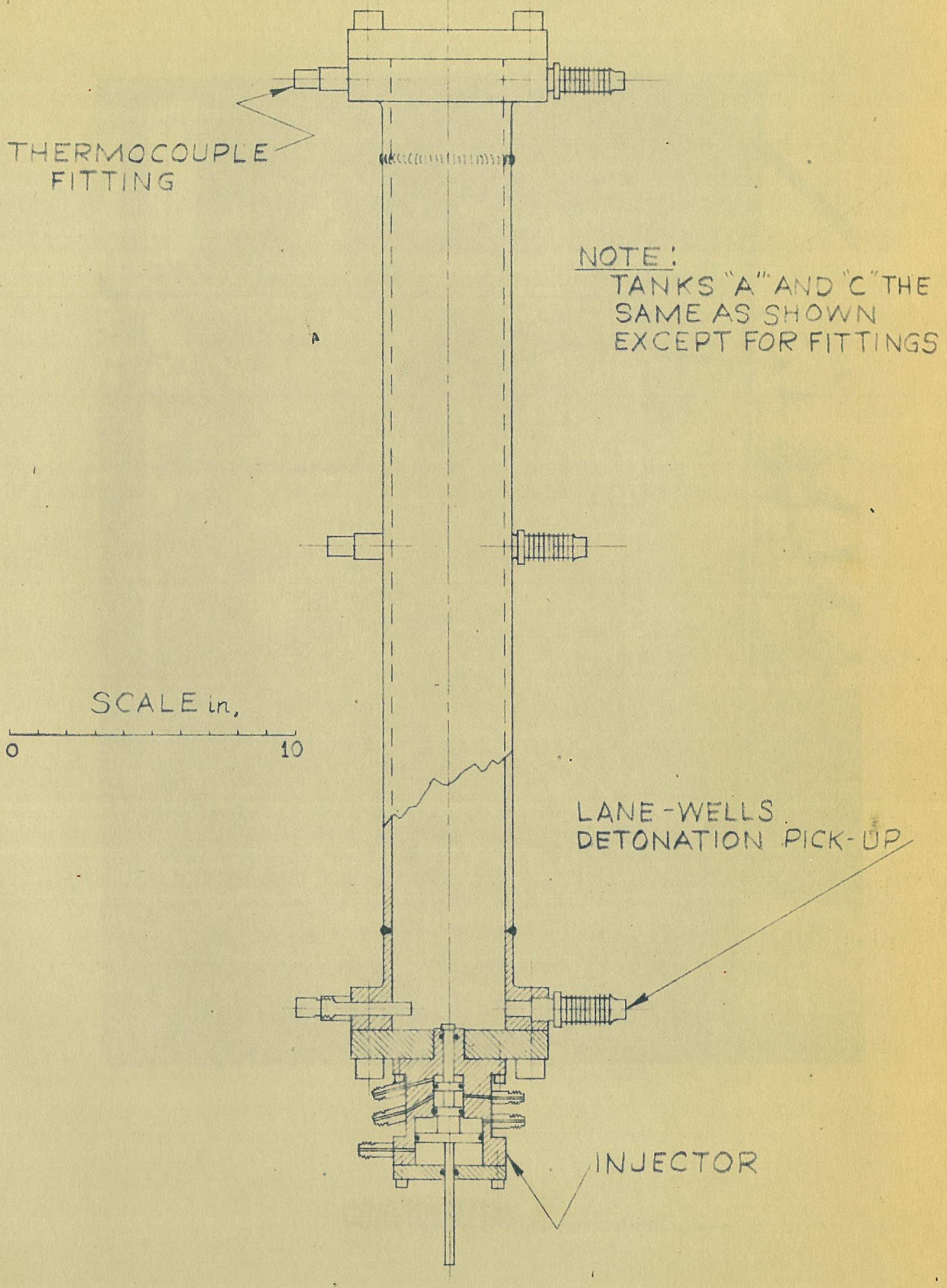


FIG. 5

[redacted]

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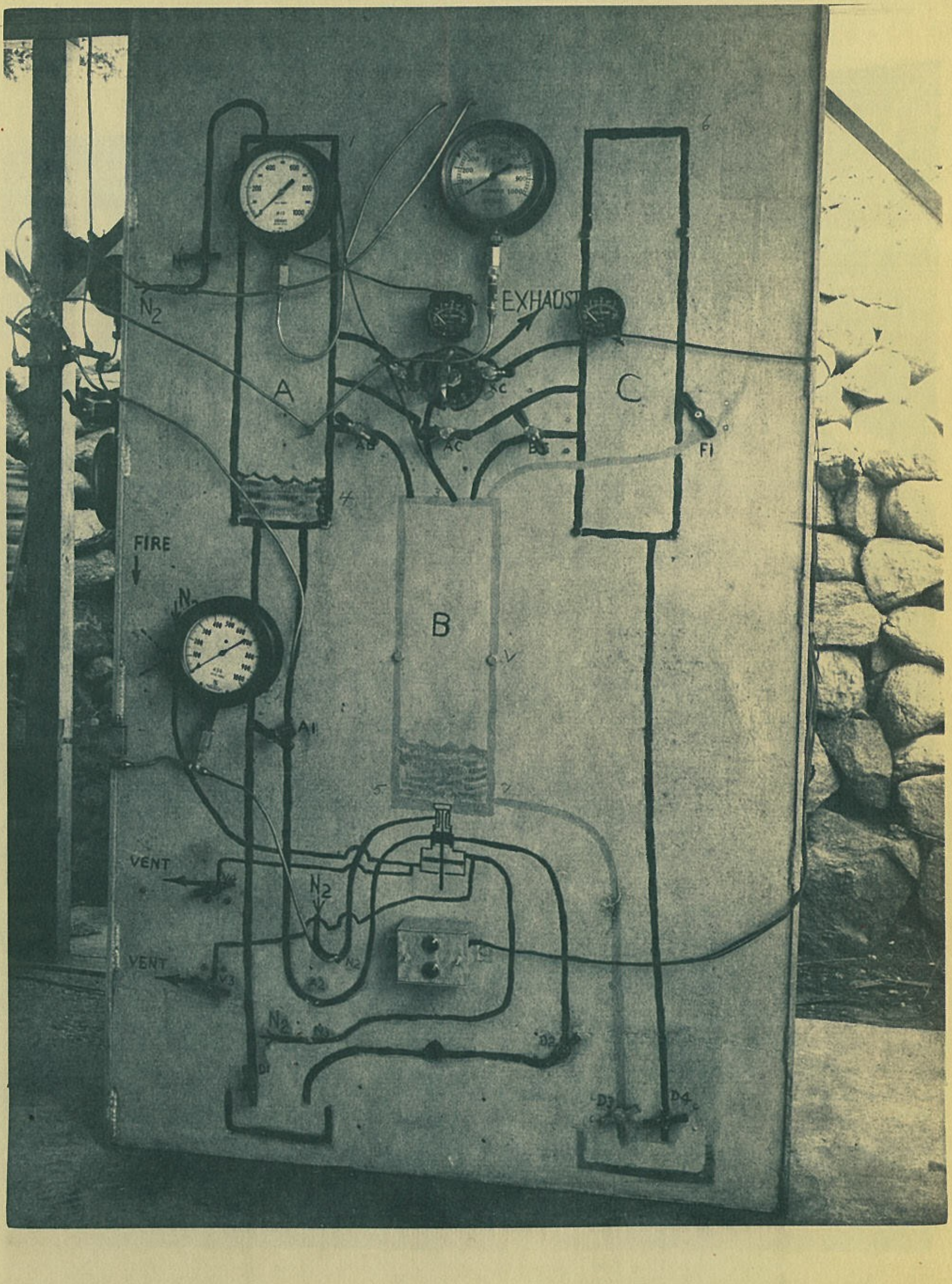

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FIG. 6

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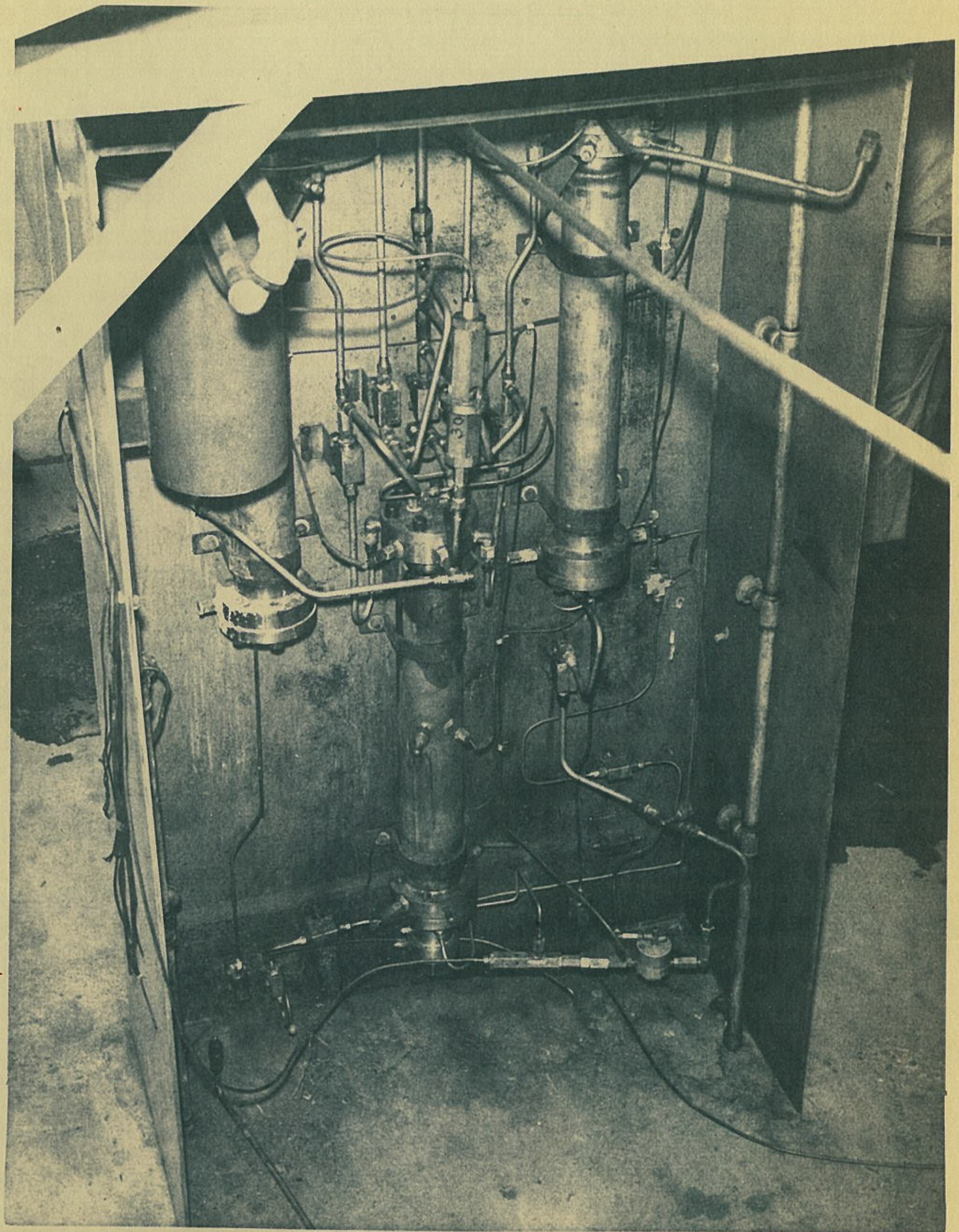


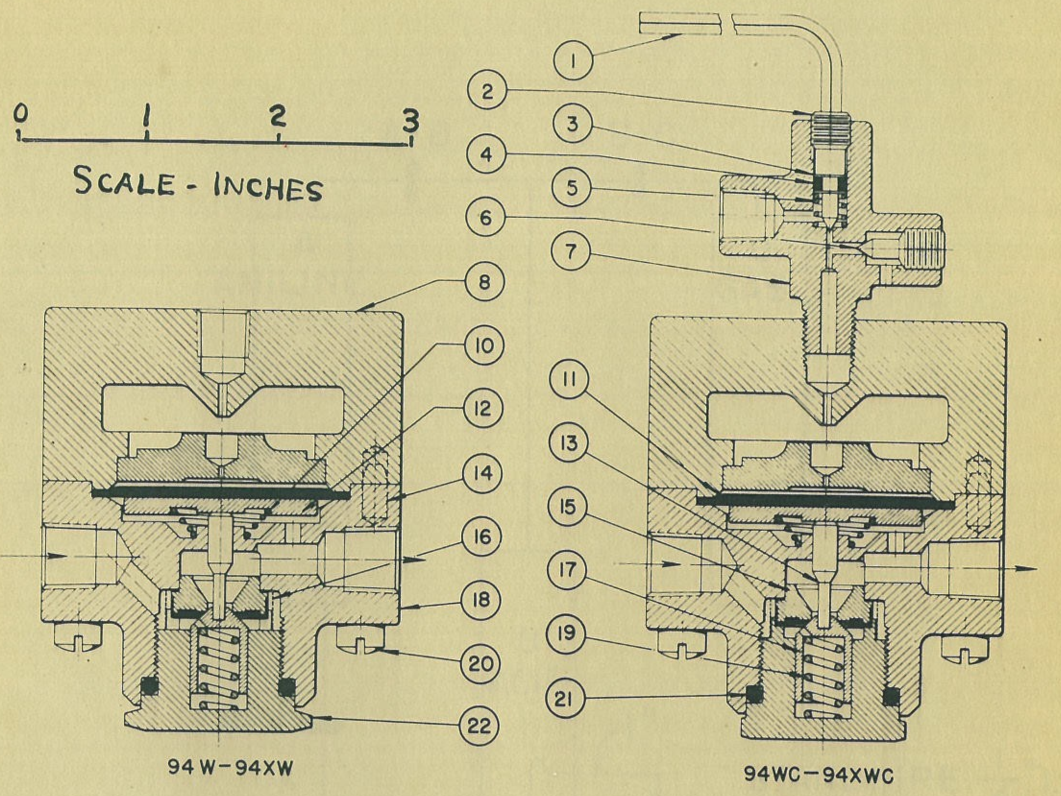
[redacted]

FIG. 7

GROVE REGULATOR CO.

1190 - 67th Street, Oakland, Calif.

PARTS LIST



Pc. No.	Name	Part No.	Qty.
1	Loading Wrench		
2	Loading Needle Valve		
3	Washer		
4	Grommet		
5	Spring		
6	Needle Valve		
7	Loading Cross Body		
8	Dome Unit		
10	Diaphragm Spring		
11	Diaphragm		
12	Diaphragm Plate		
13	Pushrod		
14	Dowel Pins		
15	Valve Seat Unit		
16	Screen		
17	Valve		
18	Body		
19	Valve Spring		
20	Capscrew		
21	Seal Ring		
22	Body Plug		

Model No.

When ordering spare or replacement parts order by Part Number and Name.

ALWAYS GIVE SERIAL NUMBER OF REDUCING REGULATOR.

FIG. 8

[redacted]

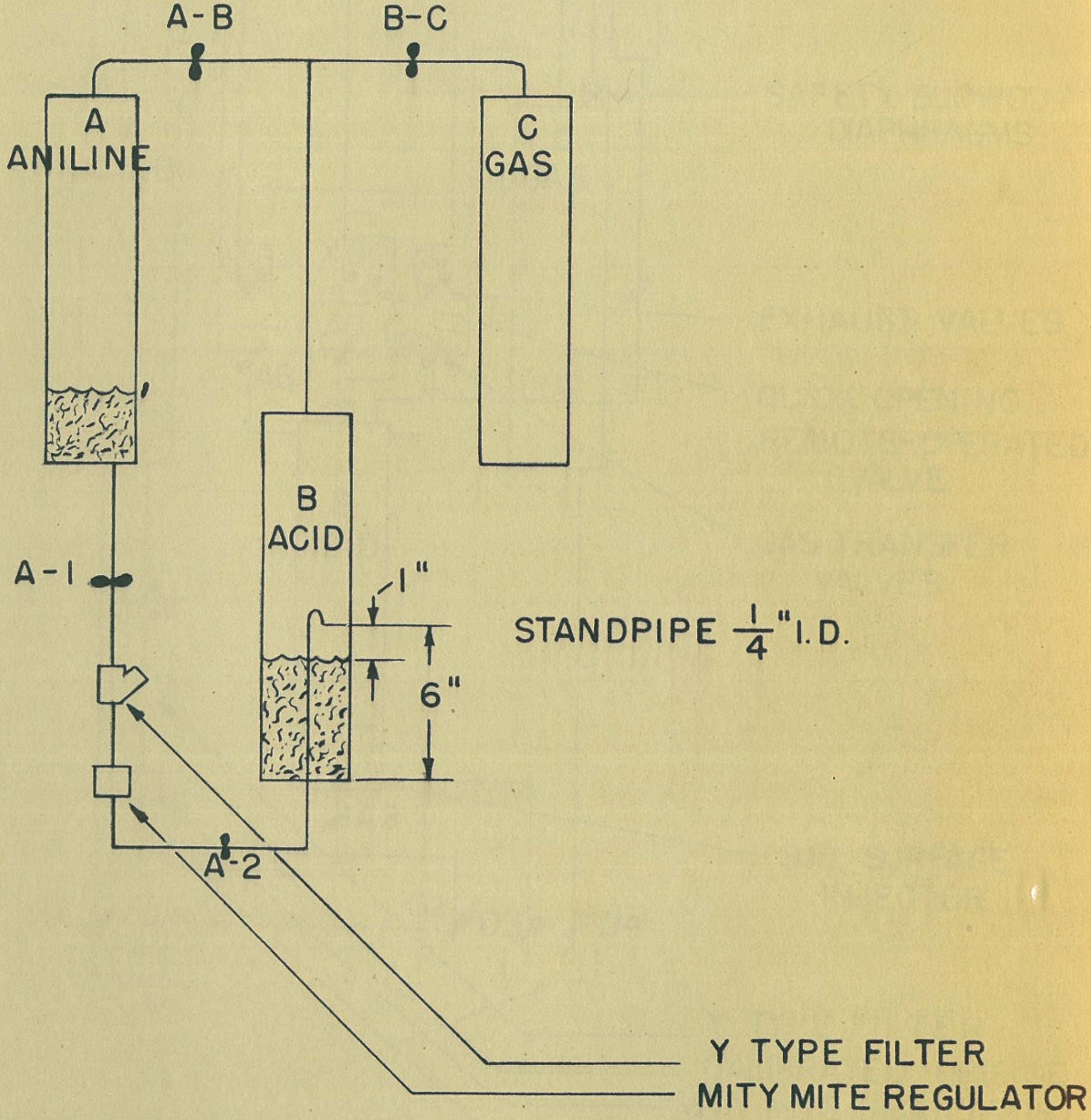
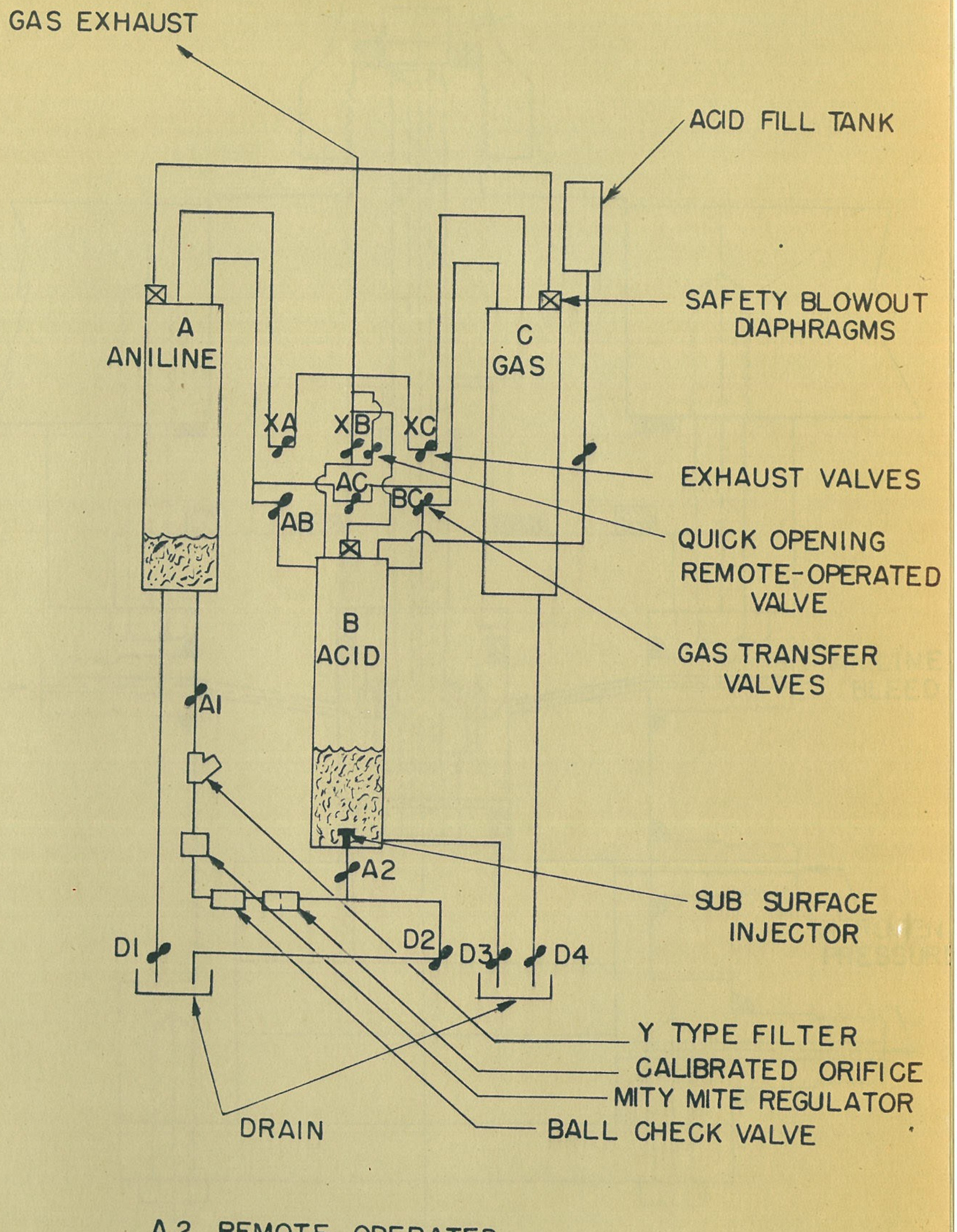


FIG. 9

[redacted]

[redacted]



A 2 REMOTE OPERATED

FIG. 10

[redacted]

[redacted]

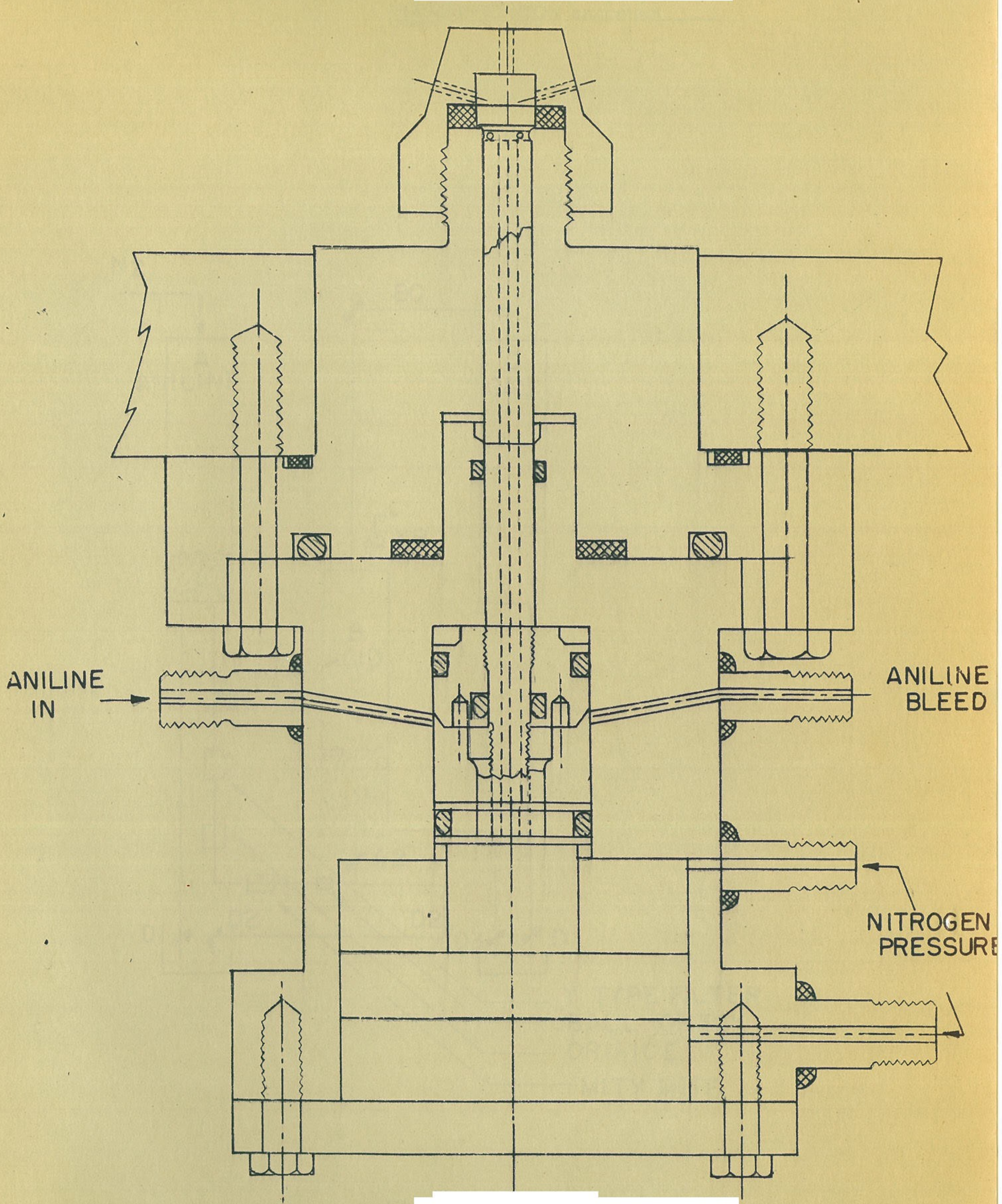


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FIG. 11

[redacted]

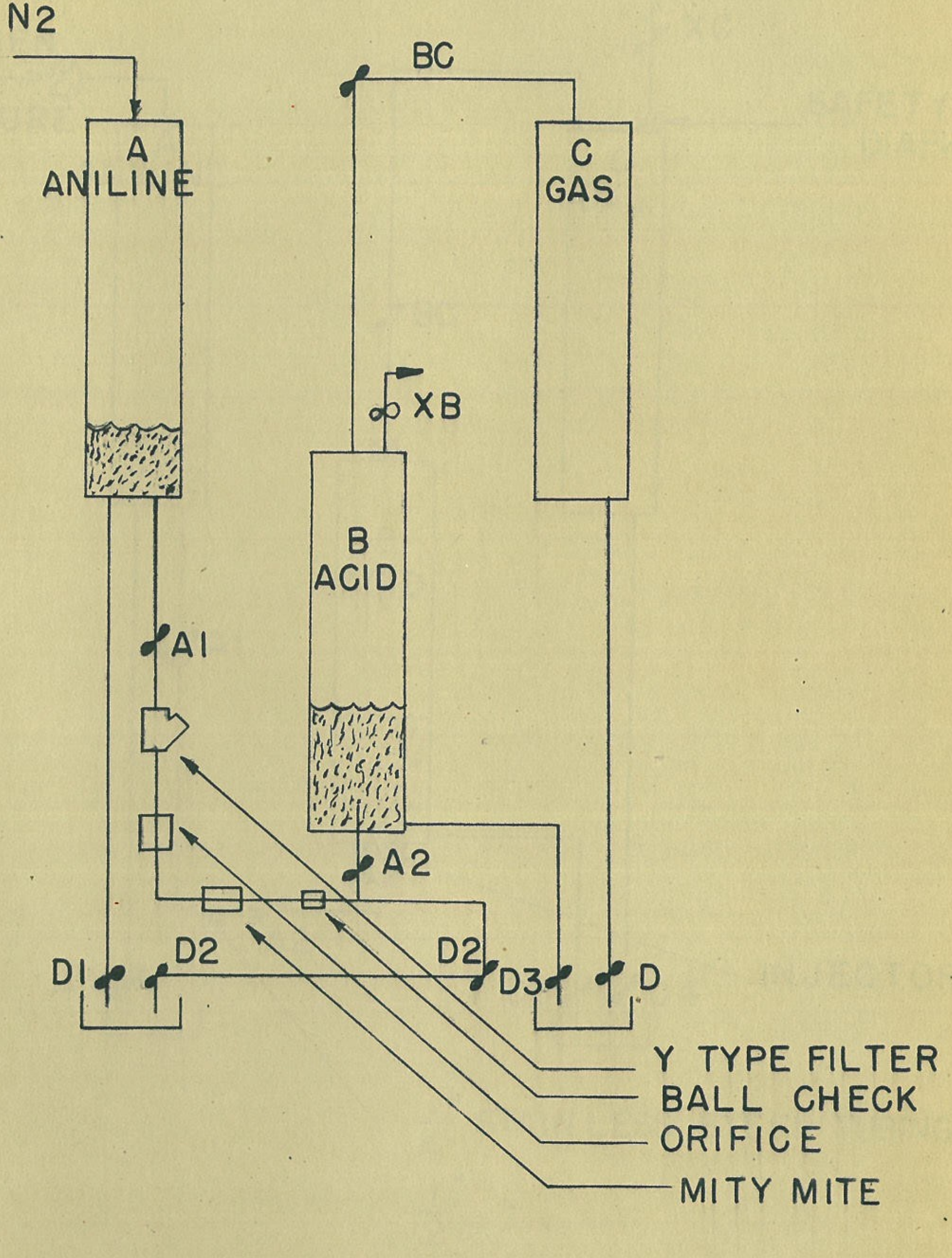


FIG. 12

[redacted]

[redacted]

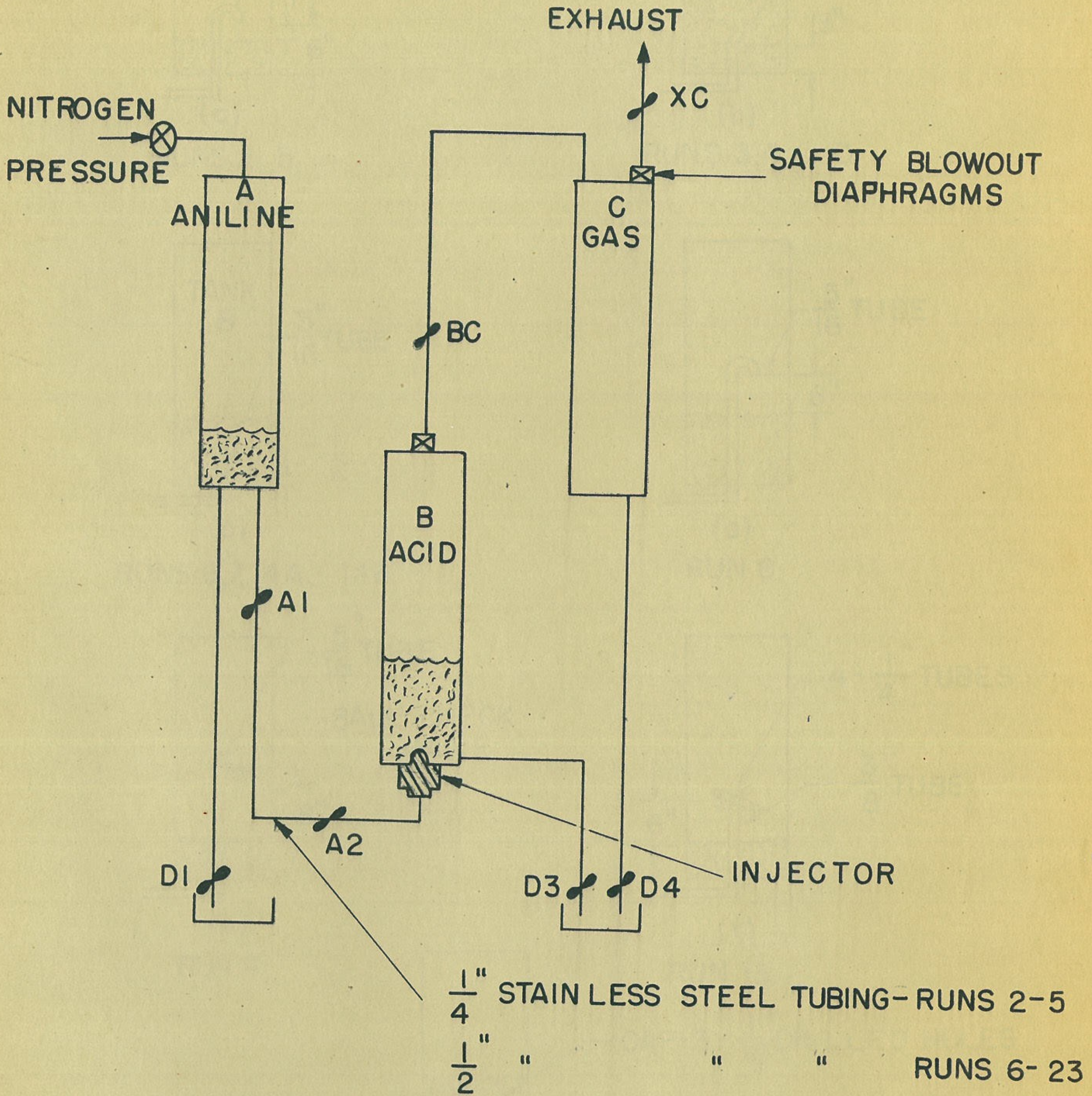
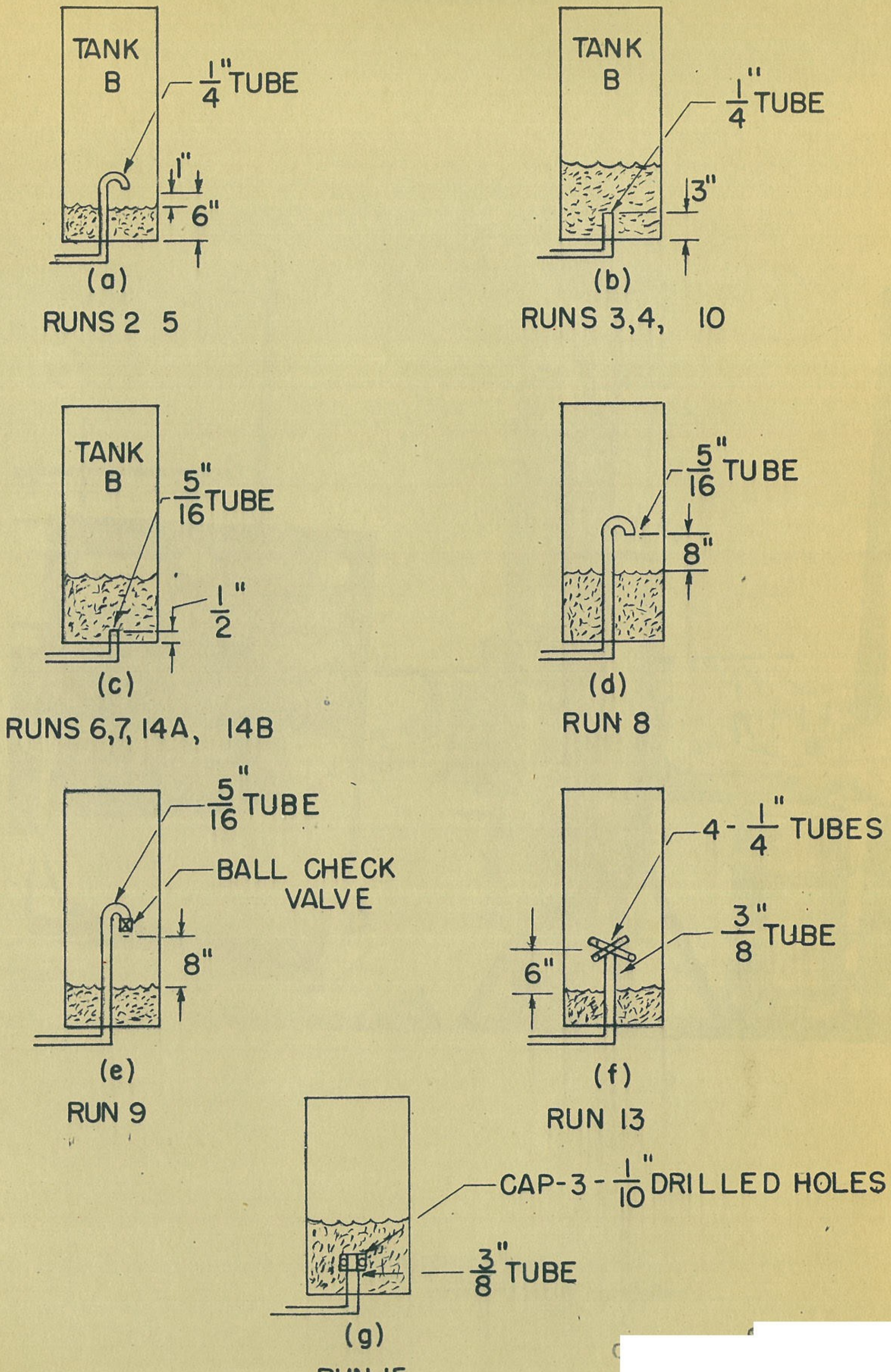


FIG. 13

[redacted]

[redacted]



(a) RUNS 2 5

(b) RUNS 3,4, 10

(c) RUNS 6,7, 14A, 14B

(d) RUN 8

(e) RUN 9

(f) RUN 13

(g) RUN 15

FIG. 14 - INJECTOR CONFIGURATIONS

[redacted]

[redacted]

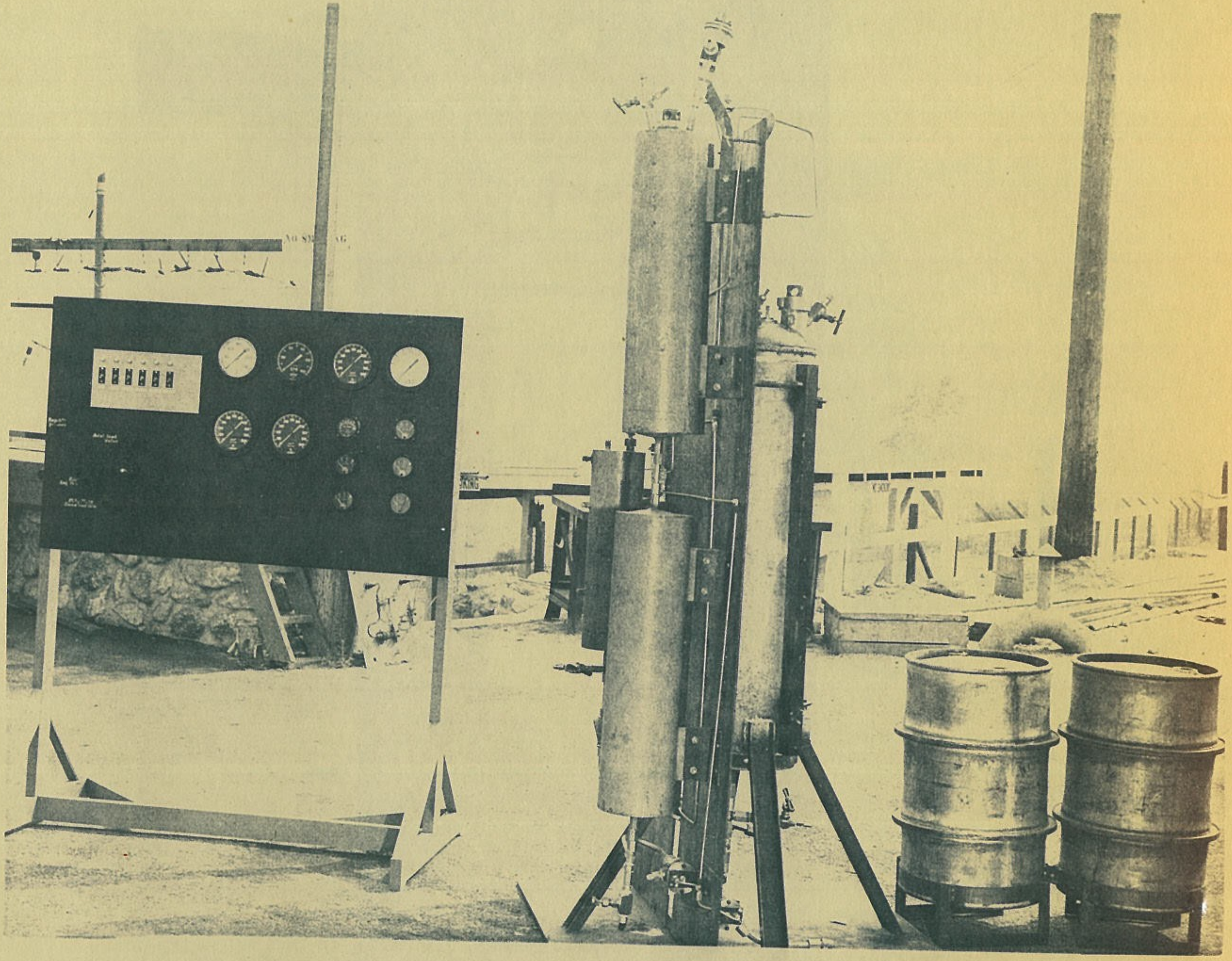


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FIG. 15

[redacted]

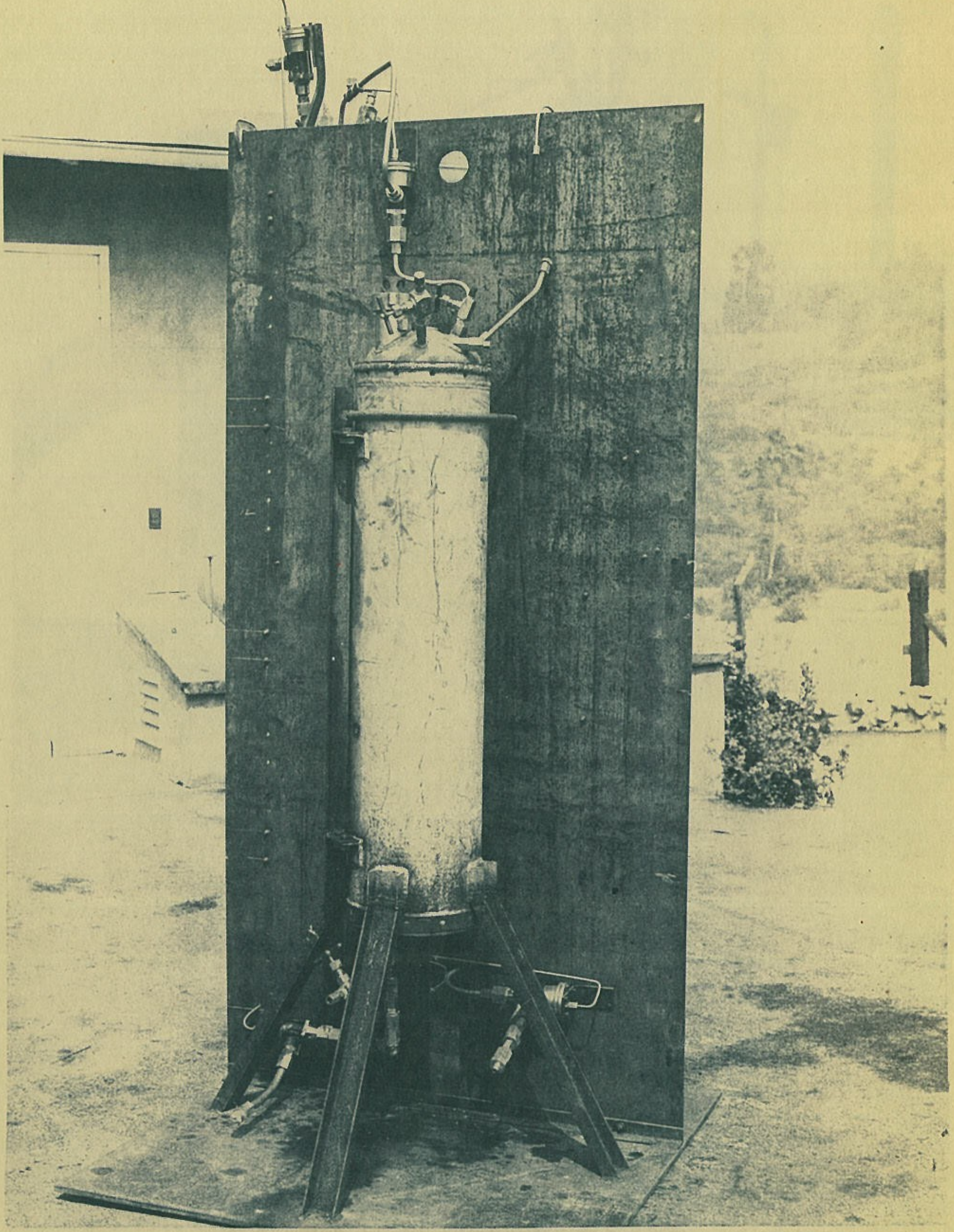

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FIG. 16 a

[redacted]

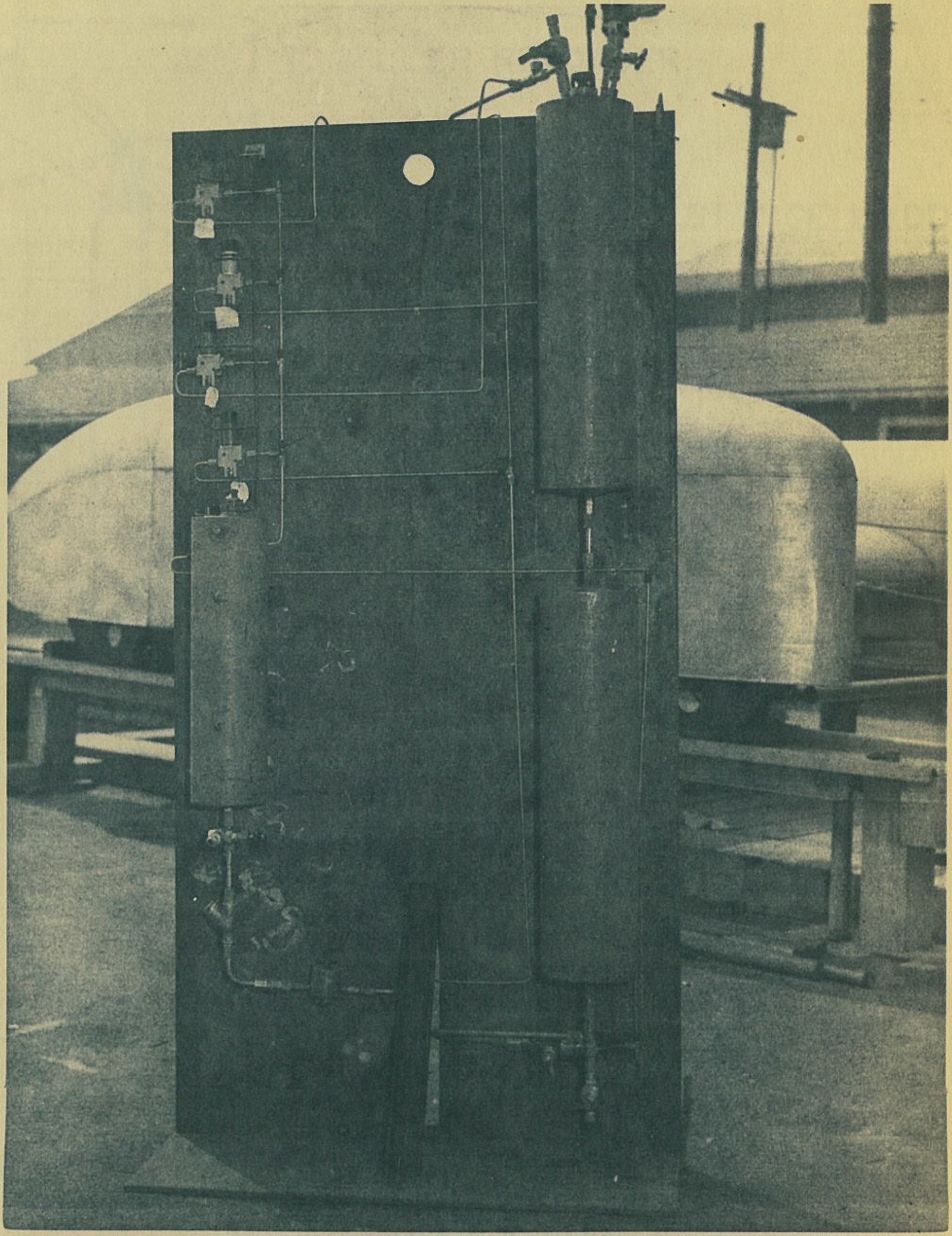

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FIG. 16b

[redacted]

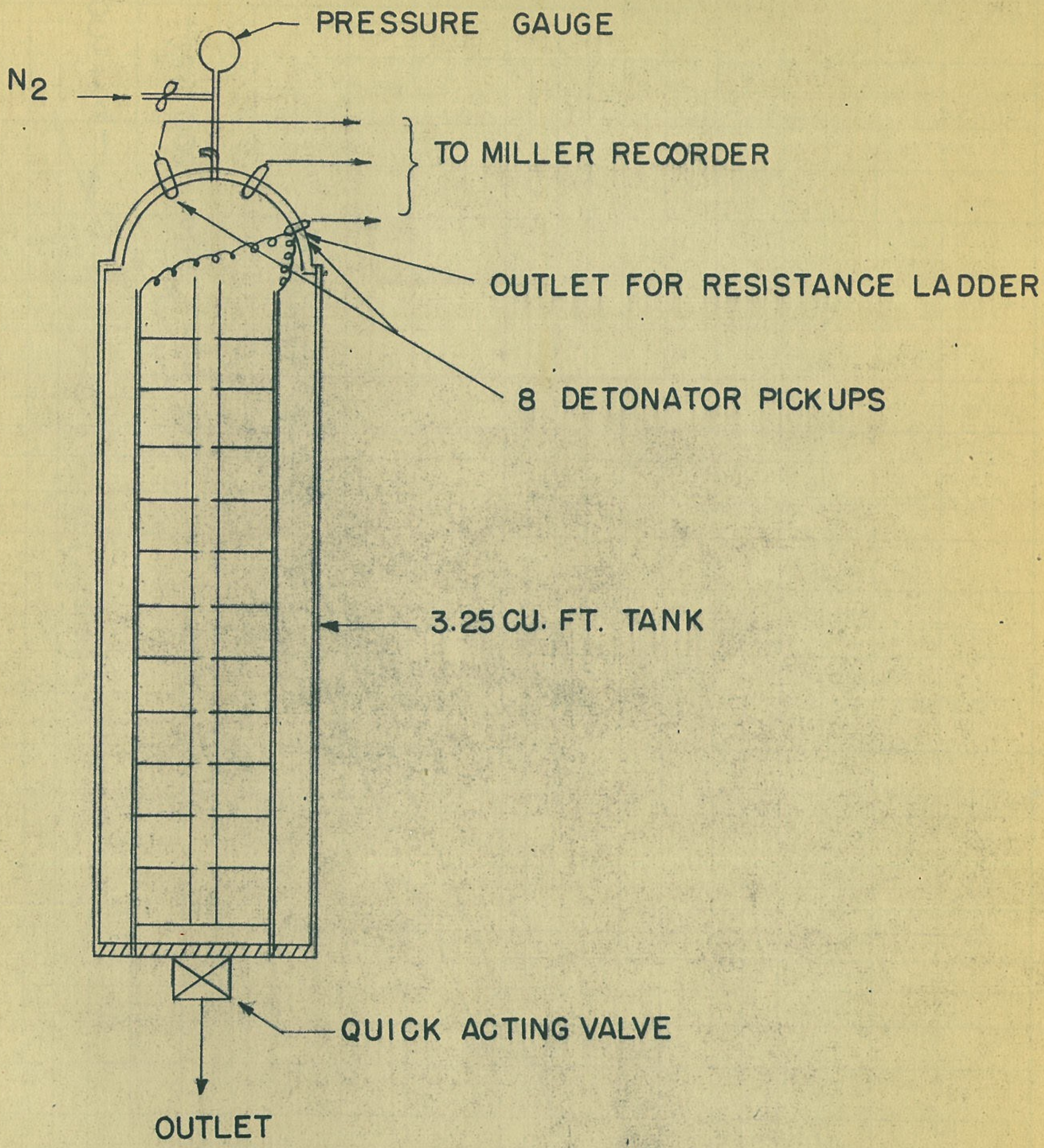

FIG. 17

[redacted]

CLASSIFICATION cancelled______

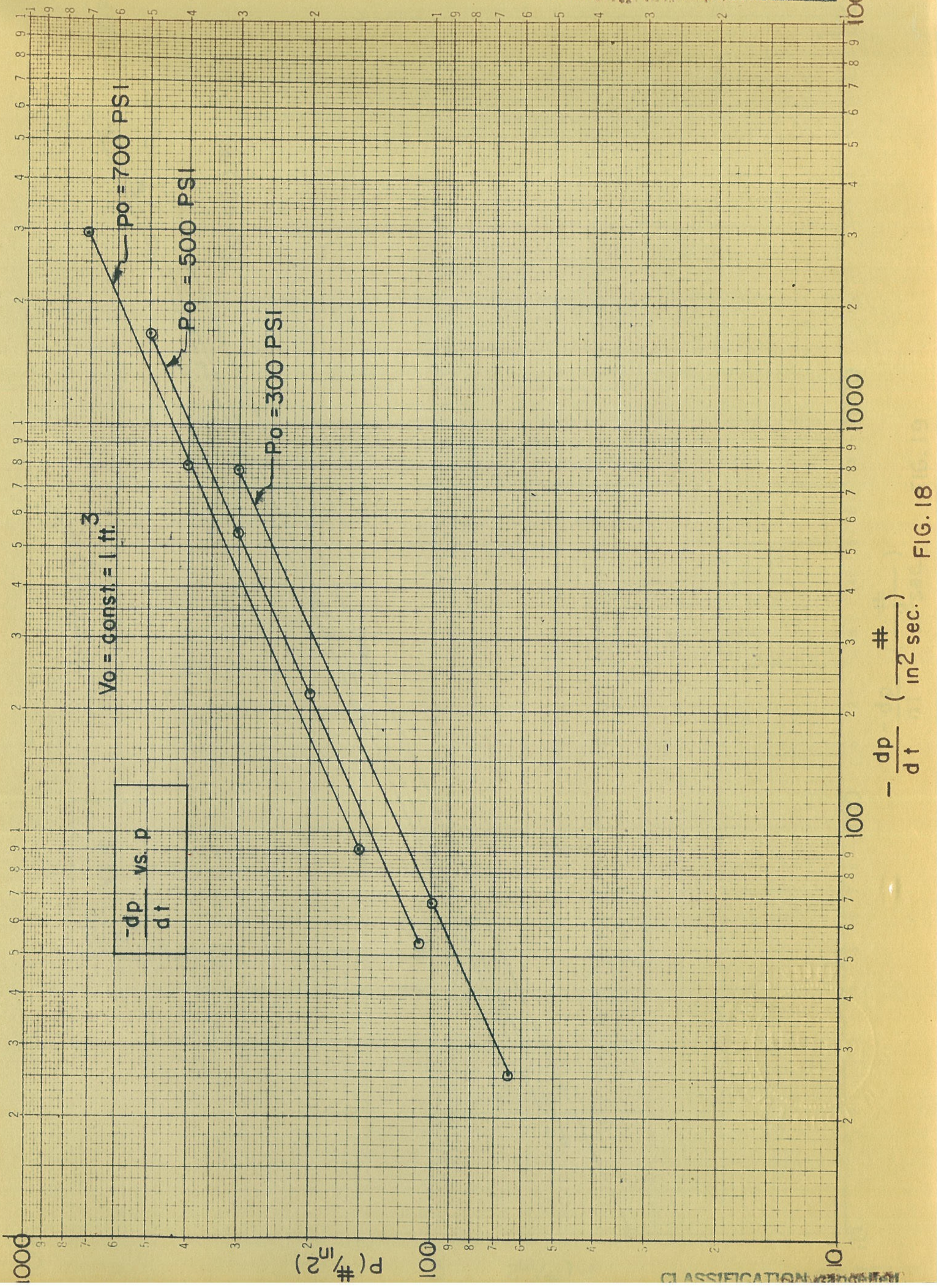

FIG. 18

CLASSIFICATION

CLASSIFICATION cancelled

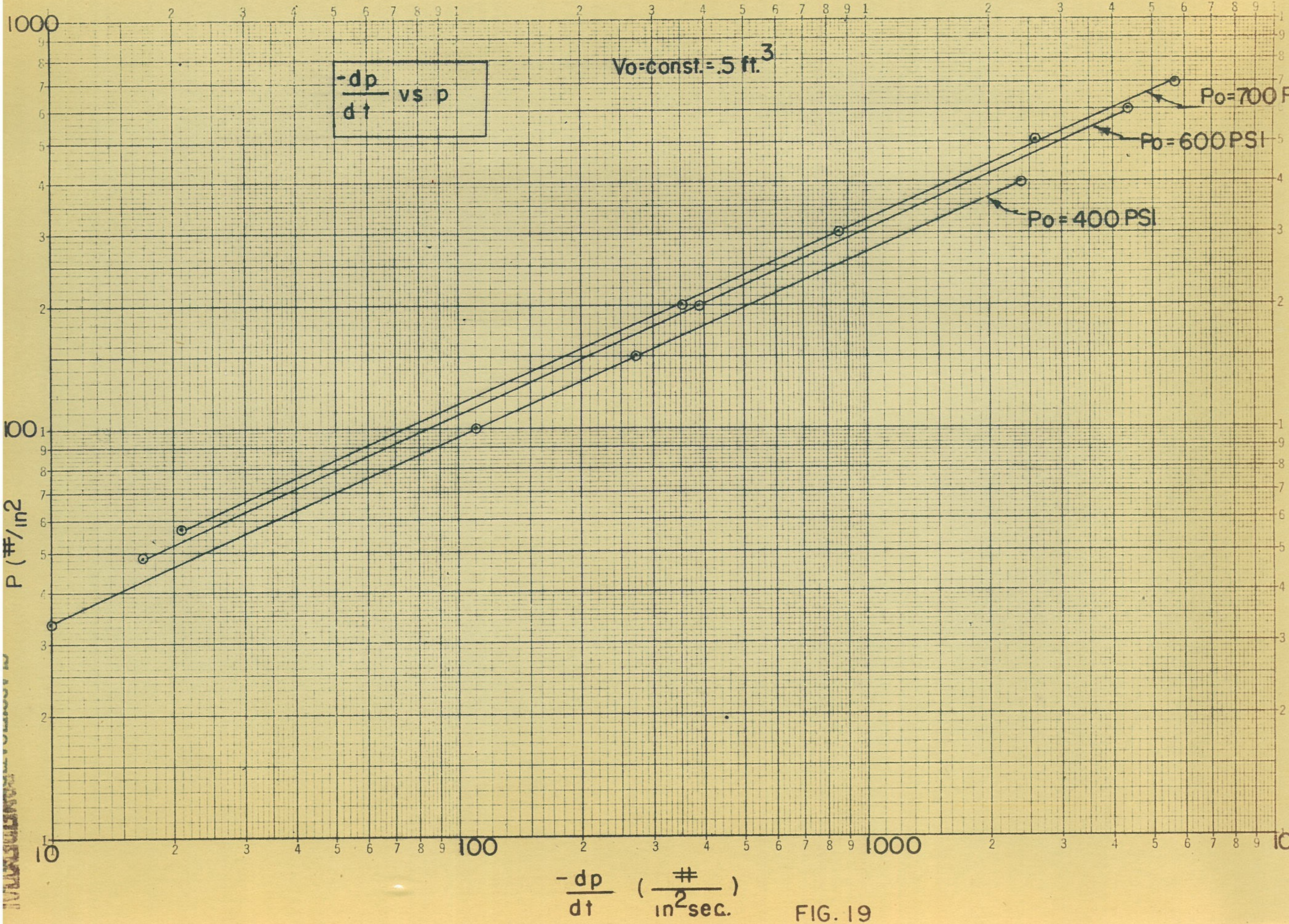

FIG. 19