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FLOW CHARACTERISTICS OF EXPLOSIVE SLURRY INJECTION SYSTEM

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An experimental program has been performed to investigate the fluid flow characteristics of aqueous, explosive slurries in a flow system which simulated the conditions present in the Picatinny Arsenal fluidized bed incinerator. Aqueous slurries containing 15, 20, and 25% weight by TNT, Composition B, HMX, and M-1 propellant were flowed above, at and below the 3.64 fps (1.109 m/sec) injection gun design flow velocity. The tests proved that all the materials can be safely flowed in this particular system, with the exception of 12 mesh or larger M1 propellant particle sizes. (over)

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The venturi flowmeter proved to be an effective means of monitoring slurry flow rate. Finally, it was found that water injected into a simulated combustion chamber, containing 0 to 6 psig (0-41.36 x ~~10^3~~ 1000 pascals) air pressure, flows at a mass flow rate which is independent of chamber pressure.

PREFACE

The work described in this report was conducted at Hazards Research Corporation, Denville, New Jersey, and was funded by the Manufacturing Technology Directorate, Picatinny Arsenal, as part of AMC Project 54114. The objective of this program was to evaluate the explosive slurry injection system of the fluidized bed incinerator pilot plant.

The explosive slurry flow experiments reported on in this program are part of the continuing effort to experimentally determine the safe operating conditions of the Picatinny Arsenal fluidized bed incinerator. This incinerator is currently under evaluation at the Arsenal. Previous work (Refs 1 and 2) determined the minimum explosive concentrations required for a detonation to propagate in the main slurry feed line of the incinerator. Personnel that contributed to the current program were Messrs. Howard Gibson and Harry McClary of Hazards Research Corporation.

TABLE OF CONTENTS

Page No.

Tables

Figures

SUMMARY

An experimental program has been performed to investigate the fluid flow characteristics of aqueous, explosive slurries in a flow system which simulated the conditions present in the Picatinny Arsenal fluidized bed incinerator. Aqueous slurries containing 15, 20 and 25% by weight of TNT, Composition B, HMX and M-1 propellant were flowed above, at and below the 3.64 fps (1.109 m/sec) injection gun design flow velocity.

The parameter of primary interest was the transport velocity required to maintain the explosive particles in suspension and thus prevent clogging. Of secondary interest was the evaluation of a venturi flowmeter as a slurry mass flow rate indicator. Finally, it was desired to develop a family of mass flow rate and flow velocity curves for each explosive material at the three solid concentrations tested. The following table summarizes the results of this program:

Summary of test program results

Material	Solids Content (Wt %)	Slurry Transport Velocities (ft/sec)	Slurry Transport Velocities (m/sec)
TNT	15	3.32 - 6.35	1.01 - 1.93
	20	2.90 - 5.49	0.88 - 1.67
	25	2.76 - 5.23	0.84 - 1.59
Comp B	15	3.47 - 6.49	1.06 - 1.98
	20	5.81 - 6.41	1.77 - 1.95
	25	5.74 - 6.50	1.75 - 1.98
HMX	15	3.64 - 6.72	1.11 - 2.05
	20	3.52 - 6.84	1.07 - 2.08
	25	3.59 - 6.80	1.09 - 2.07
M-1	15	3.48 - 6.43	1.06 - 1.96
	20	4.61 - 6.45	1.41 - 1.97
	25	4.65 - 6.45	1.42 - 1.97

In addition to the above results it was concluded that 12 mesh M-1 propellant should not be flowed in the system tested due to its tendency to clog the venturi. The venturi flowmeter proved to be an effective means of monitoring slurry flow rate. Weir type flow control valves with rubber diaphragms were found to be useless as a slurry throttling device. Finally, it was found that water injected into a simulated combustion chamber, containing 0 to 6 psig (0-41.36 x 10^3 pascals) air pressure, flows at a mass flow rate which is independent of chamber pressure.

It is recommended that further tests be performed on M-1 propellant to determine the particle size that can be pumped in the slurry injection system. In addition, a vibrating sieve (with variable screen size capability and magnetic separators) should be installed above the slurry feed tank in order to increase control over the particle size of all materials entering the slurry feed system.

INTRODUCTION

This report summarizes the results of a series of experiments performed by Hazards Research Corporation, Denville, New Jersey under the technical direction of the Modernization and Special Technology Division, of the Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey. The work was funded under Contract No. DAAA21-75-C-0104.

The objective of this program was to investigate the fluid flow characteristics of aqueous, explosive slurries in a flow system which simulated the conditions present in the Picatinny Arsenal fluidized bed incinerator. Reference 3 contains a detailed description of the incinerator. The parameter of primary interest was the transport velocity required to maintain the explosive particles in suspension throughout the slurry feed system. Of secondary interest was the feasibility of using a venturi flowmeter and pneumatically operated differential pressure transmitter to measure and record slurry mass flow rate. Finally, it was desired to establish a family of mass flow rate and velocity curves vs. recorder readings (venturi flowmeter differential pressure) for each explosive material at 15, 20 and 25% explosive weight concentrations. Information derived from this program was used to establish guidelines for incinerator operation in relation to minimum particle size of explosives and propellants, minimum slurry velocities and operational characteristics of the venturi flowmeter system.

EXPERIMENTAL PROGRAM

Materials

The following materials were supplied by Picatinny Arsenal for use in this test program:

(1) TNT, finely divided, no. 8 mesh, 28% water, lot KNK-2-3096

(2) Composition B, granular, no. 8 mesh, dry, lot HOL-052-5

(3) HMX, finely divided, no. 20 mesh, 24.8% water, lot HOL-SR-653-61

(4) M-1 propellant, no. 12 mesh, 21% water, lot PAE-03790

Hazards Research Corporation furnished the following materials:

(1) 0.250 in. schedule 40, seamless, 304 stainless steel pipe

(2) 0.250 in. schedule 10, seamless, 304 stainless steel pipe

(3) 0.374 in. i.d. Pyrex tubing

(4) Tygon flexible plastic tubing

(5) Nozzle with 0.210 in. ($.5334 \times 10^{-2}$ meters) dia. orifice

(6) Recorder chart paper

Equipment

Picatinny Arsenal supplied the following equipment:

(1) Venturi flowmeter

(2) Differential pressure transmitter, pneumatic force balance type with a 3-15 psi ($20.68-103.4 \times 10^3$ pascals) output signal

(3) Pneumatically actuated recorder

(4) Pump, peristaltic type, 4.75 gpm (17.98×10^{-3} meter^3) max. output with 0.750 in. i.d. tygon tubing at 123 rpm

(5) Variable speed agitator, 90 to 800 rpm with assorted impellers

(6) Eight gallon, (30.28×10^{-3} meter^3) cylindrical mixing tank with four adjustable baffles

(7) Weir type, flanged, hand valves with rubber diaphragms, 0.500 in. size

Description of Experiments

All flow experiments performed during this program were conducted using the experimental set-up shown schematically in Figure 1. This flow system reproduced the pipeline sizes (lengths and inside diameters) found in each of the six slurry injection systems of the Picatinny Arsenal fluidized bed incinerator. Section A to F was made from 1/4 in. sched 40 stainless steel pipe while section G to H contained 1/4 in. sched 10 stainless steel pipe. Section I to M simulated the slurry injection gun in length, inside diameter and nozzle type. The venturi flowmeter was positioned in this section as well as the glass observation pipe. The glass pipe was located as close as possible to the nozzle in order to observe any clogging that might occur at this point. In addition, it permitted observation of the slurry flow stream characteristics at various velocity levels. Total flow system length was 60 ft (18.29 meters) between sections A and M. This length corresponds to that of the incinerator slurry injection system.

The peristaltic pump used on this program provided the variable flow capability necessary to achieve a flow velocity range of 3 to 6 fps (.9144-1.8288 m/sec) in the 3/8 in. inside diameter glass pipe. It was found, after many preliminary water flow tests, that the three desired flow velocities were best achieved using 3/8, 7/16 and 1/2 in. inside diameter Tygon tubing. Design data provided by Picatinny Arsenal indicated that the lowest velocity in the injection system would be 3.64 fps at 1.5 gpm (1.109 m/sec at 9.46×10^{-5} meter^3/sec) and that it would occur at the 1/4 in. sched 10 pipe section. The use of this pump allowed tests to be conducted in this flow region. The variable speed agitator (90 to 800 rpm) with two impellers and the eight gallon, cylindrical, glass mixing tank were available from a previous program and were known to be adequate for this program. However, no attempt was made to scale this mixing system in relation to the one used on the Picatinny Arsenal incinerator. Figure 2 is a photo of the pump, agitator, weir type flow control valve and mix tank. Figure 3 presents the collection tank on the scale with the venturi flowmeter, differential pressure transmitter and glass pipe in the foreground. The pumping and mixing system is seen in the background of this photo. Figure 4 depicts the venturi flowmeter with water filled, pressure transmitting lines at its inlet section (left side) and its throat section. The glass pipe is seen connected to the outlet of the venturi. Figure 5 shows the face of the pneumatically actuated recorder with a scale of 0-10 divisions and a typical flow trace at about 9.5 divisions. Figure 6 is a close-up of the nozzle, collection tank and glass pipe. HMX slurry is seen flowing into the collection tank.

Description of Experimental Methods

Calibration of Differential Pressure Transmitter

Prior to commencing any flow tests it was necessary to calibrate the differential pressure transmitter over the anticipated range of pressure drops. Known pressures were applied to the low pressure side of the differential pressure cell while the high pressure side was sealed off. The resultant recorder deflection , 0 to 10 divisions, was then plotted against the applied pressure. This was done for 5 pressures and resulted in the calibration curve presented in Figure 7. Since all flow data presented in this report is for a specific recorder reading, the corresponding pressure drop can be found by using the calibration curve.

Calibration of Venturi Flowmeter

Two venturi flowmeters were supplied by Picatinny Arsenal for use on this program. Prior to performing aqueous, explosive slurry flow tests both units were calibrated in the flow system shown in Figure 1. A typical test commenced with the actuation of the pump and agitator with the flow control valve closed. After a constant flow was observed at the pump outlet, the flow control valve was opened and the pinch clamp was closed. This allowed all of the water to flow through the pipes, venturi and exit the nozzle into the collection tank. All tests were performed using the time required to collect ten pounds of water as the criteria for calculating flow rates. Five pounds (2.267 kilograms) of water were allowed to flow before the stop watch was activated. It was stopped after 15 pounds (6.8 kilograms) had accumulated in the collection tank. Immediately, thereafter, the pump, agitator and recorder were shut down.

Table 1 presents the tabulated results of the venturi flowmeter calibration tests for both venturies. Figures 8 and 9 contain the calibration curves which, when carefully compared, prove to be almost identical. This conforms to the design requirements.

Water Flow Tests-Pressurized Collection Tank

Since it is anticipated that the fluidized bed incinerator will have a combustion chamber pressure of 6 psig, (41.36 x 10^3 pascals) tests were conducted to determine the effect of this back pressure on water flow rate. The set-up shown in Figure 1 was used with a 7.5 gallon (28.38 x 10^{-3} meter^3) pressurized collection tank. A relief valve was affixed on top of the tank and was set to relieve at 6 psig (41.36 x 10^3 pascals). Prior to testing, 5.8 psig (39.98 x 10^3 pascals) air pressure was introduced into the chamber. The test procedure was identical to the one described above in the venturi flowmeter calibration test section. Tests were conducted both with and without chamber pressure in order to obtain data which could be readily compared.

Aqueous, Explosive Slurry Flow Tests

All aqueous, explosive slurry flow tests were conducted using the set-up shown in Figure 1. After selecting the explosive to be tested, the proportions necessary to obtain 15, 20 and 25% explosive weight concentrations were calculated. Theoretical slurry densities were also calculated in order that the velocity in the glass pipe could be found. The following table summarizes the density calculations.

Summary of slurry density calculations

	Density of slurry, (gm/cc)			
Wt, (%)	TNT	Comp B	HMX	M-1
15	1.06	1.06	1.08	1.05
20	1.09	1.09	1.10	1.06
25	1.11	1.11	1.13	1.08

Flow velocities in the 3/8 in. i.d. glass pipe were calculated using the equation:

$$\dot{W} = \rho A V$$

where:

$\dot{W}$ = mass flow rate, kg/sec
ρ = density of slurry, kg/m^3
A = flow area of glass pipe, m^2
V = flow velocity, m/sec

Flow velocity was solved for in the above equation. Density and area were constant for a given slurry concentration. Mass flow rate was the measured variable which was found by dividing 10 pounds (4.535 kg) of slurry by the time it took to collect it.

All explosive slurry tests started at the 15% by weight concentrations. The correct proportions of explosive and water were introduced into the mix tank. The agitator speed, propeller position and baffle positions were then adjusted to give an acceptable mixing pattern. With the flow control valve closed, the pump containing the 3/8 in. Tygon tubing was turned on. This caused the slurry to be circulated from the tank through the pump and back into the tank. After ten minutes of flow the valve was opened and the pinch clamp was closed. When the flow through the system stabilized, the timed 10 pound (4.535 kg) collection period commenced. After collection of exactly 10 pounds (4.535 kg) of slurry, the entire system was shut down. The test was then repeated in order to obtain an indication of the reliability of the readings. Prior to starting the second test, the suction line of the pump was moved above the settled layer of explosive in the tank. This caused clear water to flush the settled explosive out of the entire 60 ft (18.29 meters) length of pipe. In effect, this simulated the water flush system that is built into the slurry feed system of the incinerator. The theory behind that system is that at no time is the slurry allowed to settle anywhere in the feed system. A drop in slurry feed system flow rate activates a water flush system.

Prior to starting the third test, the Tygon tubing was changed to 7/16 in. in order to achieve the next velocity point. After repeating this test the tubing was changed to 1/2 in. Tygon and two more tests were performed at the maximum velocity point. In summary, the procedure used was to flow twice at each of three velocity points at each concentration of explosive. That is, there were a minimum of six tests at each concentration. There were three concentrations tested resulting in 18 flow velocity points. The mix was then discarded, the system flushed out and the tests were repeated with two more batches of the same explosive. In all, each type of explosive required a minimum of 54 flow tests. Recorder chart speed for all tests was 15 in. per minute (40.965×10^{-7} meter/sec).

Long Duration Slurry Flow Tests

The final group of tests performed on this program sought to determine the problems associated with continuous operation of the slurry feed system. This required that the discharge nozzle be removed from the collection tank and be affixed to the mixing tank. This allowed the slurry to flow through a closed loop system. Figure 10 shows the slurry flow system modified to accomplish this objective. The differential pressure transmitter, venturi flowmeter, glass pipe and nozzle is shown elevated about 4 ft (1.22 meters) above ground level.

Flow durations for this test series were about 1 hour per test. Solid explosive concentrations were 25% by weight. The recorder reading was monitored continuously for the duration of the run. If a clogging problem arose, the system was shut down, the problem eliminated and the test was continued.

There were 4 long duration tests performed on this program, one test per material. One of the objectives of this test series was to flow at the same velocity as was expected in the incinerator system. This objective was met by 1/2 in. Tygon tubing in the pump during the Comp B and TNT tests and 7/16 in. tubing for the HMX and M-1 tests.

Experimental Results

Water Flow Tests-Pressurized Collection Tank

A total of 51 water flow tests were performed to determine the effect of simulated combustion chamber pressure on water flow rate. Table 2 and Figure 11 present the results of this test effort. It can be seen that there is no significant difference between flow rates measured during the 25 tests performed with an average of 6 psig (41.36×10^3 pascals) back pressure and the 26 tests run without any chamber pressure. It was therefore concluded that all of the subsequent aqueous, explosive slurry tests would be performed by flowing into a collection tank that was open to the atmosphere.

Aqueous, Explosive Slurry Flow Tests

Tables 3, 4, 5 and 6 present the results of a total of 189 flow tests performed on aqueous slurries of TNT, Comp B, M-1 propellant and HMX. Each of these tables contain the results of 3 test series. A test series was composed of duplicate runs at 3 velocity points for each solids concentration (15, 20, and 25%). Figures 12 through 23 are plots of the data contained in the tables. Each figure contains a plot of slurry mass flow rate and flow velocity vs. recorder reading for each test series.

Long Duration, Slurry Flow Tests

Results of the 4 long duration slurry flow tests are presented in Tables 7, 8, 9 and 10. These tests each averaged 57 minutes in duration.

Discussion of Results

Aqueous, TNT Slurry Flow Tests

Of the 57 tests conducted during test series (Fig. 12, 13, 14) of Table 3, clogging occurred once (Run No. 23) at the venturi. Examination of the venturi revealed that a piece of TNT 0.20 x 0.17 in. x 0.10 in. (5.08 x 4.32 x 2.54 mm) had become lodged in the throat of the venturi. Evidently this particle had by-passed the No. 8 sieve during the grinding operation. This occurrence points out the need for rigid control of the particle sizes of all material fed into the incinerator flow system. A general rule of thumb that should be adhered to is that the particle size should be limited to 1/4 of the diameter of the smallest restriction in the flow system. On this program TNT and Comp B were sieved through No. 8 sieves, HMX through a No. 20 sieve and M-1 through a No. 12 sieve.

The following table provides a list of these screen sizes and the recommended orifice diameters:

U. S. Sieve size	Screen opening (in)	Screen opening (cm)	Orifice diameter (in)	Orifice diameter (cm)
8	0.0937	0.2380	0.3748	0.9520
12	0.0661	0.1679	0.2644	0.6716
20	0.0331	0.0841	0.1324	0.3363

There were no clogging problems due to the flow velocity being too low. The lowest velocity recorded was on Run 19, 2.76 fps (.84 m/sec). Therefore, it is safe to conclude that the transport velocity required to maintain the TNT in suspension is less than 2.76 fps (.84 m/sec).

One problem that could introduce an error into the output of the differential pressure transmitter is that of TNT foam accumulation in the plastic tubing that connects the two venturi pressure ports to the transmitter. These lines are normally completely filled with water. The water, being incompressible, transmits the pressure to the diaphragms in the pressure transmitter. HRC modified the plumbing on the transmitter by incorporating two small valves which allowed this foam to be flushed with clear water into the flow system whenever the foam build-up interfered with the pressure readings. This occurred once during the TNT test program after Run 31. Figure 24 is a photo taken prior to flushing the lines. The tubing on the left is observed to have foam throughout most of its length. This tube monitors the pressure at the throat of the venturi. The tubing on the right is clear up to the top. Inlet pressure to the venturi is transmitted by this tube to the high pressure side of the transmitter.

It is not known whether the foaming problem at the pressure transducing lines is unique to the peristaltic pump. This may be the case since there is a definite sinusoidal pulsing action visible to the naked eye and readable on the recorder traces. Since the actual incinerator slurry feed system uses a centrifugal type pump, it is possible that there will not be any foaming in the transducer lines. However, a foam layer up to 4 in. (101.6 mm) high developed in the mix tank. This same phenomena is expected to occur in the actual system. The disadvantage of this foaming action is that it changes the density of the mix and inhibits proper mixing to some degree.

Aqueous, Composition B Slurry Flow Tests

The results of the 31 tests performed on this phase of the program are presented in Table 4. Figures 15, 16 and 17 contain plots of the test data. Clogging problems developed at the nozzle when, during the first test series, an attempt was made to run at 20% solids concentration and a velocity of about 4.5 fps (1.37 m/sec). On two successive trials, the nozzle clogged on start-up. This indicated that the spherically shaped Comp B particies were not flowing at a high enough velocity to maintain a homogeneous mixture at that concentration. It was decided to run all of the remaining Comp B tests at the maximum velocity only for the 20 and 25% solids concentration tests and at all three velocity points for the 15% concentration tests. This was done and it resulted in no further clogging problems in Test Series II and III.

It is concluded that, for the Comp B particles tested on this phase of the program, the transport velocity is less that 5.7 fps (1.74 m/sec) but greater that 4.5 fps (1.37 m/sec) at solids concentration above 20% by weight.

Aqueous, M-1 Propellant Slurry Flow Tests

Table 5 contains the results of the flow test performed on M-1 propellant slurries. Figures 18, 19 and 20 present the plots of this data. M-1 proved to be the worst material tested on this program. During the first test series it clogged the venturi after 11 sec of flow time at 15% solids concentration. This resulted in the elimination of the low velocity point from the rest of the test series. Of the 45 tests performed during this phase of the program, 5 tests resulted in the clogging at the venturi. In addition, 3 cloggings occurred at the pipe manifold at the tee junction point 62 ft (18.89 meters) upstream of the nozzle. This may be unique to the HRC system and should be discounted in the evaluation of the data.

Results of the tests on this phase of the program indicate that the M-1 propellant tested can not be pumped in the system under evaluation. Elimination of the venturi might allow this material to be pumped. This would have to be evaluated in a future test program.

Aqueous, HMX Slurry Flow Tests

No clogging problems of any kind were encountered during the generation of the data shown in Table 6 and Figures 21, 22 and 23. These tests were the least troublesome of all of the tests performed. The transport velocity of the HMX tested is below 3.59 fps (1.09 m/sec) as indicated by the successful flowing at this velocity. The lack of problems it attributed to the small particle size of the HMX. Its average size is 1/3 that of the Comp B and TNT and 1/2 that of the M-1. Figure 25 is a photograph of the HMX slurry flowing in the glass pipe. It is seen that the mixture is homogeneous and no settling out occurs within the pipe.

It is concluded that the 20 mesh HMX tested on this program will not clog up the incinerator slurry feed system at the design conditions that presently exist.

Long Duration Aqueous, Explosive Slurry Flow Tests

The 57 minute duration, 25% TNT slurry flow test results presented in Table 7 reveal that there are no clogging problems associated with flow velocities of 4.50 to 4.85 fps (1.37-1.48 m/sec). Foam in the differential pressure cell lines did not interrupt the test since it was flushed from the lines as required. This flushing procedure was performed without shutting down the test.

No system clogging problems were experienced during the 56.5 minute duration, Comp B slurry flow test (Table 8). Flow velocities were fairly stable as shown by the 6.35 to 6.60 fps (1.93-2.01 m/sec) flow range. No flushing of the differential pressure cell transducer lines was required for this test.

The problems experienced during the short duration, M-1 flow tests were repeated during the 56.8 minute duration test reported on in Table 9. This test had to be interrupted many times due to clogging of either the venturi or the nozzle. It is concluded that the M-1 propellant tested on this program can not be flowed in the present slurry injection system.

A 55 minute duration HMX slurry flow test was performed with no clogging or foaming problems. As shown by Table 10, the flow data was the most stable of all 4 materials tested. It appears that HMX can be flowed in the incinerator slurry injection system as per design requirements.

Weir Type, Flow Valves With Rubber Diaphragms

A by-product of the over 100 preliminary system tests performed on this program was the evaluation of the weir type flow valves as a throttling device. Originally the tee shown in Figure 1 contained 2 valves. Three velocity points were to be obtained by varying the flow areas in these valves. The peristaltic pump was to use a 1/2 in. i.d. Tygon tube. This would have given a flow rate of 2 gpm (12.6×10^{-5} meter^3/sec). This would have been enough to provide the 3 velocity points selected for study. Water flow tests using this throttling concept were successful. However, when TNT slurry flow tests were attempted it was found that the flows were erratic. One could not set a flow point and maintain it for more than a few seconds. For example, a recorder reading of 5 divisions would jump up to 9 divisions for a period of time and then go off scale. It is posited that this phenomena was caused by the continuous build-up and break-away of solid TNT particles on the surface of the rubber diaphragm. After many unsuccessful trials it was decided that the valves could only be used as "on" - "off" flow control devices in slurry applications.

It was then decided to vary flow velocity using 3 different size plastic tubes in the pump and eliminate one of the flow control valves. The control valve shown at the tee section in Figure 1 was used in the full open and full closed position only for the duration of all tests performed on this program.

Evaluation of Venturi Flowmeter as a Slurry Flow Indicator

The venturi flowmeter and the differential pressure transmitter with the pneumatic recorder proved to be an effective system for monitoring explosive slurry flow rates. It continuously monitored the slurry flow stream and rapidly reflected changes in slurry concentration. An example of this is shown in Figure 26. This recorder trace represents HMX slurry test number 161. The 9.35 division readout was recorded when clear water was flowing through the venturi. Opening of the flow control valve resulted in a 20% HMX slurry flow through the venturi. This was immediately reflected by a rise in the trace to 9.8 divisions. Clogging at the venturi resulted in the recorder pen being driven off scale past the 10 division line. Examination of the data also reveals that this system was reproducible and no zero shifts were experienced. The major disadvantage of this system is the requirement for 100% control over the particle size of the material introduced into the flow system. A second disadvantage is the question of explosive foam being introduced into the pressure transducer lines. This phenomena causes an error in the differential pressure reading and also contaminates the high and low sides of the differential pressure cell with fine explosive dust. This second disadvantage may not be valid if future testing with the centrifugal pump reveals that no foam gets into the lines.

CONCLUSIONS

As a result of the many aqueous, explosive slurry flow experiments conducted on this program, it is possible to conclude the following for the specific materials studied in the slurry flow system described in Figure 1:

1. Slurries containing 25% TNT by weight can be flowed in the slurry injection system tested at flow velocities of 2.76 to 5.23 fps (.84-1.59 m/sec).
2. Slurries containing 25% Composition B by weight can be flowed in the slurry injection system tested at flow velocities of 5.60 to 6.5 fps (1.7-1.98 m/sec).
3. Slurries containing 25% HMX by weight can be flowed in the slurry injection system tested at flow velocities of 3.59 to 6.8 fps (1.09-2.07 m/sec).
4. Twelve mesh M-1 propellant cannot be flowed in the system tested.
5. The venturi flowmeter, pneumatic differential pressure transmitter and pneumatic recorder flow monitoring system tested is an effective means of monitoring slurry flow rate.
6. Water injected into a simulated combustion chamber, containing 0 to 6 psig (0-41.36 x 10^3 pascals) air pressure, flows at a mass flow rate which is independent of chamber pressure.

It should be noted that conclusions 1 through 4 only apply to the specific particle sizes tested for each material. The transport velocity for solids in a liquid carrier is a function of pipe diameter, particle size, particle density, liquid density, slurry density, and liquid viscosity.

RECOMMENDATIONS

It is recommended that implementation of the following items be considered:

1. That the flow monitoring (D/P Transmitter) technology evaluated under this program be expanded for use in other applications without the venturi, where a discernible pressure drop exists in process lines. This could be accomplished by utilizing two pressure transmitters across the pressure drop, the D/P transmitter, and the flow monitor. This would also prevent the instrument lines from clogging with explosive slurry.

2. Perform further flow tests on M-1 propellant to determine the particle size that can be pumped in the slurry injection system.

3. Install a vibrating sieve (with variable screen size capability and magnetic separators) above the slurry feed tank in order to increase control over the particle size of all materials entering the slurry feed system.

REFERENCES

1. G. Petino, Jr. and D. Westover, "Detonation Propagation Tests on Aqueous Slurries of TNT, Composition B, M-9 and M-10", Technical Report 4584, Picatinny Arsenal, Dover, New Jersey, November 1973

2. G. Petino, Jr. and D. Westover, "Detonation Propagation Tests on Aqueous Slurries of RDX, HMX, M-1 and Nitrocellulose", Contractor Report ARLCD-CR-77002

3. I. Forsten, J. S. Santos and R. Scola, "Development Trends in the Incineration of Waste Explosives and Propellants," Technical Memorandum 2209, Picatinny Arsenal, Dover, New Jersey, May 1976.

Table 1

Results of venturi water flow calibration tests

Test Series	Run No.	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
I	1	5.50	10	55.6	10.79	3.76	Test series I was performed on venturi with S/N 611647-1.
	2	5.50	10	55.2	10.87	3.78	
	3	7.15	10	42.0	14.29	4.97	
	4	7.15	10	41.8	14.35	4.99	
	5	8.75	10	34.0	17.65	6.14	
	6	8.75	10	34.0	17.65	6.14	
II	7	5.25	10	58.8	10.20	3.55	Test series II was performed on venturi with S/N 611647-2.
	8	5.35	10	57.0	10.50	3.66	
	9	7.30	10	41.8	14.34	5.00	
	10	7.30	10	41.4	14.52	5.06	
	11	9.05	10	32.8	18.30	6.38	
	12	9.07	10	33.0	18.18	6.33	

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[a] Water vel in 3/8 in. i.d. glass pipe.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 2

Results of water flow tests to determine effect of chamber pressure on flow rate

Run No.	Recorder Reading (0-10 div)[b]	Flow Parameters				Chamber Press.[f] (psig)
		Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	
1	4.0	10	80.2	7.48	2.6	5.7 to 5.8
2	4.3	10	78.6	7.63	2.7	5.8 to 5.8
3	4.3	10	73.4	8.17	2.8	5.8 to 5.9
4	4.5	10	70.8	8.47	3.0	5.6 to 5.8
5	4.7	10	67.6	8.88	3.1	5.8 to 6.0
6	6.2	10	49.3	12.17	4.2	5.8 to 6.0
7	6.5	10	46.8	12.82	4.5	5.8 to 6.0
8	7.2	10	41.5	14.45	5.0	5.8 to 6.0
9	8.8	10	34.0	17.65	6.1	5.8 to 6.1
10	9.0	10	33.5	17.91	6.2	5.8 to 6.2
11	9.2	10	32.3	18.58	6.5	5.8 to 6.3
12	9.5	10	31.4	19.11	6.7	6.0 to 6.3
13	4.3	10	73.0	8.22	2.9	6.0 to 6.0
14	4.9	10	65.0	9.23	3.2	6.0 to 6.0
15	4.9	10	64.0	9.38	3.3	5.9 to 6.0
16	4.9	10	64.8	9.26	3.2	5.9 to 6.0

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[a] Water vel in 3/8 in. i.d. glass pipe.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert from psig to pascals multiply by 6.894×10^{3}.

Table 2

Results of water flow tests to determine effect of chamber pressure on flow rate (cont)

Run No.	Recorder Reading (0-10 div)[b]	Flow Parameters				Chamber Press.[f] (psig)
		Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	
17	3.0	10	112.0	5.36	1.9	5.7 to 5.7
18	3.0	10	111.1	5.40	1.9	5.6 to 6.0
19	2.9	10	117.5	5.11	1.8	6.0 to 6.0
20	2.8	10	120.8	4.97	1.7	6.0 to 6.1
21	3.3	10	98.3	6.10	2.1	6.0 to 6.1
22	3.1	10	111.5	5.38	1.9	6.0 to 6.2
23	3.4	10	95.0	6.32	2.2	6.0 to 6.2
24	3.5	10	93.6	6.41	2.2	6.0 to 6.2
25	2.2	10	177.0	3.39	1.2	6.0 to 6.0
26	5.0	10	60.0	10.00	3.5	0
27	7.4	10	48.7	12.32	4.3	0
28	7.4	10	41.8	14.35	5.0	0
29	7.6	10	39.2	15.38	5.3	0
30	7.7	10	39.0	15.38	5.4	0
31	5.1	10	62.4	9.62	3.3	0
32	5.1	10	61.8	9.71	3.4	0

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[a] Water vel in 3/8 in. i.d. glass pipe.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert from psig to pascals multiply by 6.894×10^{3}.

Table 2

Results of water flow tests to determine effect of chamber pressure on flow rate (cont)

Run No.	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Chamber Press. (psig)
33	5.1	10	61.7	9.72	3.4	0
34	5.1	10	60.3	9.95	3.5	0
35	4.2	10	73.6	8.15	2.8	0
36	4.2	10	75.0	8.00	2.8	0
37	4.2	10	73.8	8.13	2.8	0
38	4.3	10	74.6	8.04	2.8	0
39	9.2	10	32.5	18.46	6.4	0
40	9.5	10	31.3	19.16	6.7	0
41	9.6	10	31.0	19.35	6.7	0
42	9.7	10	31.0	19.35	6.7	0
43	8.5	10	35.5	16.90	5.9	0
44	1.8	10	216.0	2.78	1.0	0
45	2.8	10	117.5	5.11	1.8	0
46	3.1	10	103.2	5.81	2.0	0
47	3.0	10	107.8	5.57	1.9	0
48	3.1	10	104.9	5.72	2.0	0

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[a] Water vel in 3/8 in. i.d. glass pipe.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 2

Results of water flow tests to determine effect of chamber pressure on flow rate (cont)

Run No.	Recorder Reading (0-10 div)[b]	Flow Parameters				Chamber Press. (psig)
		Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	
49	3.5	10	90.9	6.60	2.3	0
50	3.4	10	94.8	6.33	2.2	0
51	3.4	10	94.7	6.34	2.2	0

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[a] Water vel in 3/8 in. i.d. glass pipe.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 3

Results of aqueous, explosive slurry flow tests

Material : TNT

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Flow Parameters Time (sec)	Flow Parameters Rate (lb/min)[d]	Flow Parameters Vel[a] (fps)[e]	Remarks
I	1	15	9. 15	10	31. 0	19. 34	6. 35	Density of sample = 1. 16 gm/cc at 15%.
	2	15	8. 95	10	31. 4	19. 10	6. 27	
	3	15	6. 85	10	44. 8	13. 38	4. 39	TNT slurries developed 4 inches of foam on the surface of the 12 inch diameter mix tank during all pumping tests.[f]
	4	15	6. 85	10	44. 9	13. 35	4. 39	
	5	15	5. 30	10	59. 4	10. 10	3. 32	
	6	15	5. 30	10	58. 4	10. 28	3. 40	
	7	20	5. 60	10	56. 0	10. 71	3. 42	Density of sample = 1. 30 gm/cc at 20%.
	8	20	5. 60	10	56. 4	10. 62	3. 40	
	9	20	6. 95	10	45. 4	13. 20	4. 22	Density measurements are not accurate due to foaming problem.
	10	20	6. 95	10	45. 8	13. 10	4. 19	
	11	20	8. 55	10	36. 0	16. 68	5. 33	
	12	20	8. 70	10	35. 0	17. 16	5. 49	
	13	25	8. 65	10	36. 0	16. 68	5. 23	Density of sample = 1. 46 gm/cc at 25%.
	14	25	7. 40	10	43. 6	13. 74	4. 31	
	15	25	7. 80	10	42. 4	14. 16	4. 44	No clogging problems were encountered during this test series.
	16	25	6. 40	10	51. 0	11. 76	3. 69	
	17	25	5. 60	10	61. 0	9. 84	3. 09	
	18	25	5. 10	10	66. 4	9. 06	2. 84	
	19	25	5. 10	10	68. 2	8. 80	2. 76	

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[a] Slurry vel in 3/8 in. i. d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert inches to millimeters multiply by 25. 4

Table 3

Results of aqueous, explosive slurry flow tests (cont)

Material: TNT

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Flow Parameters Time (sec)	Flow Parameters Rate (lb/min)[d]	Flow Parameters Vel[a] (fps)[e]	Remarks
II	20	15	5.60	10	53.6	11.20	3.70	Density of sample = 1.10 gm/cc at 15%.
	21	15	5.60	10	55.8	10.74	3.52	
	22	15	6.90	10	43.4	13.80	4.53	Run No. 23, venturi clogged by piece of TNT 0.20 in.x 0.17 in.x 0.10 in. after 10 sec of flow time.[g]
	23[f]	15	6.95	-	10.0	-	-	
	24	15	7.05	10	42.8	14.22	4.60	
	25	15	8.70	10	34.0	17.64	5.80	
	26	15	8.77	10	34.0	17.64	5.80	
	27	20	8.70	10	35.0	17.16	5.49	Density of sample = 1.25 gm/cc at 20%.
	28	20	8.75	10	35.2	17.04	5.45	
	29	20	6.85	10	47.4	12.66	4.05	Flushed low pressure line between venturi and differential pressure cell after Run No. 31 to remove TNT foam.
	30	20	6.75	10	47.6	12.60	4.03	
	31	20	5.50	10	58.8	10.20	3.25	
	32	20	5.55	10	59.2	10.14	3.23	
	33	25	5.70	10	56.4	10.62	3.33	Density of sample = 1.18 gm/cc at 25%.
	34	25	5.60	10	56.8	10.56	3.31	
	35	25	6.70	10	49.0	12.24	3.84	
	36	25	6.75	10	48.4	12.42	3.89	
	37	25	8.27	10	38.2	15.72	4.93	
	38	25	8.40	10	39.0	15.36	4.82	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See remarks column.

[g] To convert inches to millimeters multiply by 25.4

Table 3

Results of aqueous, explosive slurry flow tests (cont)

Material: TNT

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Flow Parameters Time (sec)	Flow Parameters Rate (lb/min)[d]	Flow Parameters Vel[a] (fps)[e]	Remarks
III	39	15	5.75	10	52.9	11.34	3.73	Density of sample = 1.14 gm/cc at 15%.
	40	15	5.70	10	54.4	11.04	3.62	
	41	15	7.00	10	43.4	13.80	4.53	No clogging problems were encountered during this test series
	42	15	7.00	10	41.6	14.40	4.73	
	43	15	8.95	10	32.2	18.66	6.13	
	44	15	9.05	10	32.2	18.66	6.13	
	45	20	8.70	10	35.0	17.16	5.49	Density of sample = 1.38 gm/cc at 20%.
	46	20	8.65	10	36.4	16.50	5.28	
	47	20	6.50	10	51.2	11.70	3.75	
	48	20	6.70	10	50.2	11.94	3.82	
	49	20	5.25	10	66.4	9.06	2.90	
	50	20	5.50	10	64.8	9.24	2.95	
	51	25	5.50	10	64.8	9.24	2.90	Density of sample = 1.46 gm/cc at 25%.
	52	25	5.50	10	60.8	9.90	3.11	
	53	25	6.55	10	54.4	11.04	3.46	
	54	25	6.60	10	52.6	11.40	3.58	
	55	25	6.55	10	51.4	11.70	3.67	
	56	25	8.25	10	43.6	13.74	4.31	
	57	25	8.20	10	41.8	14.34	4.49	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 4

Results of aqueous, explosive slurry flow tests

Material: Composition B

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Flow Parameters Time (sec)	Flow Parameters Rate (lb/min)[d]	Flow Parameters Vel[a] (fps)[e]	Remarks
I	58	15	5.60	10	56.4	10.62	3.49	Density of sample = 1.07 gm/cc at 15%.
	59	15	5.65	10	54.0	11.10	3.65	
	60	15	7.05	10	43.0	13.98	4.59	
	61	15	7.05	10	43.4	13.80	4.53	
	62	15	8.95	10	34.6	17.34	5.70	
	63	15	9.05	10	32.0	18.78	6.17	
	64	20	8.90	10	32.6	18.42	5.89	Run No. 66, nozzle clogged at start-up on each of two attempts to flow at 4.0 fps velocity range. Abandoned low velocity trials and completed flows at high velocity point for all 20 and 25% concentrations on this mix and all succeeding mixes of Composition B.
	65	20	8.80	10	33.0	18.18	5.81	
	66[f]	20	-	-	-	-	-	
	67	25	8.95	10	33.4	17.94	5.74	
	68	25	8.85	10	34.2	17.52	5.60	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See Remarks column.

Table 4

Results of aqueous, explosive slurry flow tests (cont)

Material: Composition B

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
II	69	15	5.60	10	53.4	11.22	3.69	Density of sample = 1.05 gm/cc at 15%.
	70	15	5.80	10	55.0	10.92	3.59	
	71	15	7.10	10	41.8	14.34	4.71	No clogging problems were encountered during this test series.
	72	15	7.10	10	42.0	14.28	4.69	
	73	15	9.30	10	30.4	19.73	6.49	
	74	20	9.40	10	30.0	19.98	6.39	
	75	20	9.50	10	30.0	20.04	6.41	
	76	25	9.50	10	29.0	20.70	6.50	
	77	25	9.60	10	29.0	20.70	6.50	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 4

Results of aqueous, explosive slurry flow tests (cont)

Material: Composition B

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
III	78	15	5.65	10	55.4	10.86	3.56	Density of sample = 1.07 gm/cc at 15%.
	79	15	5.65	10	56.8	10.56	3.47	
	80	15	5.65	10	54.6	10.98	3.61	No clogging problems were encountered during this test series.
	81	15	7.05	10	42.0	14.28	4.69	
	82	15	7.10	10	42.2	14.22	4.67	
	83	15	9.35	10	31.0	19.38	6.37	
	84	15	9.30	10	30.8	19.50	6.41	
	85	20	9.50	10	30.0	19.98	6.39	
	86	20	9.60	10	30.0	19.98	6.39	
	87	25	9.65	10	29.4	20.4	6.40	
	88	25	9.75	10	29.0	20.7	6.50	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 5

Results of aqueous, explosive slurry flow tests

Material: M-1 Propellant

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters				Remarks
				Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	
I	89[f]	15	5.50	-	11.0	-	-	Run No. 89, venturi clogged after 11 sec of flow time. Flow velocity estimated to be 3.5 fps. Eliminated this low velocity point from the test series.
	90	15	8.85	10	33.0	18.18	6.03	
	91	15	8.90	10	33.0	18.18	6.03	
	92	15	6.85	10	45.0	13.32	4.42	
	93	15	6.95	10	43.8	13.68	4.54	
	94	20	7.05	10	41.5	14.46	4.75	Subsequent to Run No. 89, test procedure was modified to include clear water flush of system prior to performing the next test.
	95	20	7.00	10	42.7	14.04	4.61	
	96[f]	20	9.10	-	17.0	-	-	
	97	20	9.10	10	31.4	19.11	6.27	
	98	20	9.10	10	31.4	19.11	6.28	
	99	25	9.05	10	30.6	19.62	6.33	Run No. 96, clogged pipe manifold at tee junction point 62 feet upstream of nozzle after 17 sec of flow.[g]
	100	25	9.10	10	30.6	19.62	6.33	
	101	25	7.00	10	41.4	14.50	4.68	
	102	25	7.00	10	41.6	14.42	4.65	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See Remarks column.

[g] To convert feet to meters multiply by .3048.

Table 5

Results of aqueous, explosive slurry flow tests (cont)

Material: M-1 Propellant

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
II	103	15	7.25	10	41.0	14.64	4.86	Density of sample = 1.02 gm/cc at 15%.
	104	15	7.15	10	42.0	14.28	4.74	Run No. 106, clogged low pressure port of venturi after 11 sec of flow.
	105	15	9.07	10	31.6	18.99	6.30	
	106[f]	15	9.15	-	11.0	-	-	
	107[f]	15	8.80	-	2.0	-	-	Run No. 107, recorder drove off scale after 2 sec of flow. No clogging could be found. A slug of propellant probably momentarily clogged venturi.
	108	15	9.00	10	31.6	18.99	6.30	
	109[f]	20	9.20	-	13.0	-	-	
	110	20	9.25	10	31.4	19.08	6.26	Run No. 109, clogged inlet side of venturi.
	111	20	9.20	10	33.0	18.18	5.97	
	112[f]	20	7.15	10	41.2	14.58	4.79	
	113	20	7.20	10	41.4	14.52	4.77	Density of sample = 1.07 gm/cc at 20%.
	114[f]	25	7.30	10	40.4	14.88	4.80	Density of sample = 1.04 gm/cc at 25%.
	115	25	7.30	10	40.0	15.00	4.84	Run No. 112, tee clogged on start-up. Cleaned out tee and repeated test.
	116	25	9.35	10	30.2	19.86	6.40	
	117	25	9.30	10	30.0	19.98	6.45	Run No. 114, tee clogged on start-up. Cleaned out tee and repeated test.

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See Remarks column.

Table 5

Results of aqueous, explosive slurry flow tests (cont)

Material: M-1 Propellant

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Flow Parameters Time (sec)	Flow Parameters Rate (lb/min)[d]	Flow Parameters Vel[a] (fps)[e]	Remarks
III	118	15	5.35	10	56.4	10.62	3.52	Density of sample = 1.04 gm/cc at 15%.
	119	15	5.40	10	57.2	10.50	3.48	
	120	15	7.15	10	41.8	14.34	4.76	
	121	15	7.15	10	42.0	14.28	4.74	
	122	15	9.15	10	31.0	19.38	6.43	
	123	15	9.20	10	31.2	19.26	6.39	
	124	20	9.40	10	30.6	19.62	6.45	
	125	20	9.30	10	30.8	19.50	6.41	
	126	20	7.20	10	41.0	14.64	4.81	
	127	20	7.20	10	41.2	14.58	4.79	
	128	25	7.30	10	40.0	15.00	4.84	Density of sample = 1.05 gm/cc at 25%.
	129	25	7.35	10	40.2	14.94	4.82	Run No. 130, inlet of venturi clogged
	130[f]	25	9.35	-	22.0	-	-	after 22 sec of flow time.
	131	25	9.20	10	30.6	19.62	6.33	
	132[f]	25	9.20	-	25.0	-	-	Run No. 132, inlet of venturi clogged
	133	25	9.25	10	30.8	19.50	6.28	after 25 sec of flow time.

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See Remarks column.

Table 6

Results of aqueous, explosive slurry flow tests

Material: HMX

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
I	134	15	9.40	10	29.6	20.28	6.54	Density of sample = 1.07 gm/cc at 15%.
	135	15	9.60	10	29.4	20.40	6.58	
	136	15	7.25	10	40.0	15.00	4.84	No clogging problems were encountered during this test series.
	137	15	7.30	10	40.0	15.00	4.84	
	138	15	5.55	10	53.0	11.34	3.66	
	139	15	5.60	10	52.8	11.34	3.66	
	140	20	5.60	10	44.0	13.62	4.31	Density of sample = 1.06 gm/cc at 20%.
	141	20	5.65	10	51.1	11.76	3.73	
	142	20	5.70	10	51.2	11.70	3.71	Flushed low and high pressure lines between venturi and differential pressure cell after Run No's. 146 and 149.
	143	20	7.35	10	39.2	15.30	4.85	
	144	20	7.40	10	37.8	15.90	5.04	
	145	20	9.40	10	29.1	20.64	6.54	
	146	20	9.50	10	29.3	20.46	6.48	
	147	25	9.65	10	27.9	21.50	6.63	Density of sample = 1.10 gm/cc at 25%.
	148	25	9.70	10	28.4	21.13	6.51	
	149	25	7.55	10	36.9	16.26	5.01	
	150	25	7.55	10	37.3	16.09	4.96	
	151	25	5.80	10	50.6	11.86	3.66	
	152	25	5.80	10	50.0	12.00	3.70	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 6

Results of aqueous, explosive slurry flow tests (cont)

Material: HMX

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters				Remarks
				Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	
II	153	15	5.65	10	51.8	11.58	3.74	Density of sample = 1.07 gm/cc at 15%.
	154	15	5.70	10	51.4	11.70	3.77	
	155	15	7.35	10	39.8	15.06	4.86	No clogging problems were encount-
	156	15	7.30	10	39.6	15.18	4.90	ered during this test series.
	157	15	9.50	10	29.0	20.70	6.68	Run No. 160, scale mechanism
	158	15	9.45	10	29.3	20.46	6.60	jammed.
	159	20	9.65	10	28.2	21.30	6.75	Density of sample = 1.10 gm/cc at 20%.
	160[f]	20	9.80	-	9.0	-	-	
	161	20	9.70	10	28.8	20.82	6.60	
	162	20	6.95	10	41.0	14.64	4.64	
	163	20	7.10	10	41.2	14.58	4.62	
	164	20	5.45	10	52.8	11.34	3.59	
	165	20	5.50	10	54.2	11.10	3.52	
	166	25	5.60	10	50.1	12.00	3.70	Density of sample = 1.13 gm/cc at 25%.
	167	25	5.60	10	51.6	11.64	3.59	
	168	25	7.45	10	38.3	15.67	4.83	Flushed low and high pressure lines
	169	25	7.45	10	37.0	16.21	5.00	between venturi and differential
	170	25	9.85	10	27.2	22.06	6.80	pressure cell after Run No's. 156,
	171	25	9.85	10	28.6	20.98	6.47	162 and 167.

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] See Remarks column.

Table 6

Results of aqueous, explosive slurry flow tests (cont)

Material: HMX

Test Series	Run No.	Solids Conc (%)	Recorder Reading (0-10 div)[b]	Flow Parameters Wt (lbs)[c]	Time (sec)	Rate (lb/min)[d]	Vel[a] (fps)[e]	Remarks
III	172	15	5.60	10	51.7	11.58	3.74	Density of sample = 1.12 gm/cc at 15%.
	173	15	5.60	10	53.2	11.28	3.64	
	174	15	7.30	10	39.6	15.18	4.90	Flushed low and high pressure lines between venturi and differential pressure cell after Run No's. 176, 181 and 185.
	175	15	7.35	10	38.2	15.72	5.07	
	176	15	9.65	10	28.8	20.82	6.72	
	177	15	9.70	10	29.0	20.69	6.67	
	178	20	9.75	10	27.8	21.58	6.84	Density of sample = 1.09 gm/cc at 20%.
	179	20	9.75	10	28.5	21.05	6.67	
	180	20	7.40	10	37.6	15.96	5.06	
	181	20	7.45	10	38.5	15.58	4.94	
	182	20	5.70	10	52.8	11.36	3.60	
	183	20	5.70	10	51.1	11.74	3.72	
	184	25	5.80	10	48.0	12.48	3.85	Density of sample = 1.10 gm/cc at 25%.
	185	25	5.80	10	49.4	12.12	3.74	
	186	25	7.60	10	36.2	16.57	5.11	No clogging problems were encountered during this test series.
	187	25	7.60	10	37.2	16.13	4.97	
	188	25	10.00	10	27.6	21.72	6.70	
	189	25	10.00	10	27.2	22.06	6.80	

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[a] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at specified solids conc.

[b] See calibration curve, Fig 7.

[c] To convert from lbs to kg multiply by 4.535924×10^{-1}.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 7

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% TNT

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a] Rate (lb/min)[d]	Flow Parameters[a] Vel[b] (fps)[e]	Remarks[f]
8.0	1.0	14.0	4.55	One in. thick layer of TNT foam in mix tank.
8.0	5.0	14.0	4.55	Three in. thick layer of TNT foam in mix tank. Diff. press. cell lines half full of foam.
8.4	10.0	15.0	4.85	Four in. thick layer of TNT foam in mix tank. Diff. press. cell lines half full of foam.
8.2	12.5	14.5	4.70	Diff. pressure cell lines clogged. Flushed lines with clear water.
8.3	17.0	14.7	4.80	Foam formed in diff. press. cell lines.
8.2	19.0	14.5	4.70	Tygon tubing in pump ruptured. Replaced it and continued test.
8.1	25.0	14.2	4.65	Diff. Press. lines half full of foam.
7.9	30.0	13.9	4.50	One in. thick layer of foam in mix tank. Flushed lines with clear water.

---

[a] Values taken off plot shown in Fig 14.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert inches to millimeters multiply by 25.4

Table 7

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% TNT (cont)

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a] Rate (lb/min)[d]	Vel[b] (fps)[e]	Remarks[f]
8.3	35.0	14.7	4.80	Diff. press. cell lines half full of foam.
8.4	40.0	15.0	4.85	Diff. press. cell lines half full of foam.
8.2	45.0	14.5	4.70	One in. thick layer of foam in mix tank.
8.3	47.0	14.7	4.80	Flushed diff. press. cell lines with water.
8.3	51.0	14.7	4.80	No problems.
8.2	55.0	14.5	4.70	No problems.
8.2	57.0	14.5	4.70	End of test. No clogging problems in nozzle or venturi. Foaming a problem in diff. press. cell lines.

---

[a] Values taken off plot shown in Fig 14.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert inches to millimeters multiply by 25.4.

Table 8

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% Composition B

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a]		Remarks[f]
		Rate (lb/min)[d]	Vel[b] (fps)[e]	
9.5	1.0	20.0	6.35	No problems.
9.7	5.0	20.5	6.50	No problems.
9.8	10.0	20.8	6.60	Three-quarter in. thick layer of Comp. B foam in mix tank.
9.8	15.0	20.8	6.60	No change from above condition.
9.8	20.0	20.8	6.60	Foam in diff. press. cell lines was three-quarters of an in. thick.
9.8	25.0	20.8	6.60	Low pressure side of diff. press. cell had 2 in. of foam in its line.
9.7	30.0	20.5	6.50	Low pressure side of diff. press. cell had 4 in. of foam in its line.
9.8	37.0	20.8	6.60	Low pressure side of diff. press. cell had 6 in. of foam in its line.
9.6	40.0	20.2	6.40	No change in foaming condition in mix tank and lines to diff. press. cell.
9.6	45.0	20.2	6.40	No change in conditions.
9.5	51.0	20.0	6.35	Low pressure side of diff. press. cell had 8 in. of foam in its line.

---

[a] Values taken off plot shown in Fig 17.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert inches to millimeters multiply by 25.4.

Table 8

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% Composition B (cont)

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a] Rate (lb/min)[d]	Vel[b] (fps)[e]	Remarks[f]
9.5	55.0	20.0	6.35	No change in conditions.
9.5	56.5	20.0	6.35	Low pressure side of diff. press. cell had 10 in. of foam in its line and 2 in. in its high side line. End of test. No clogging problems in nozzle or venturi.

---

[a] Values taken off plot shown in Fig 17.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

[f] To convert inches to millimeters multiply by 25.4.

Table 9

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% M-1

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a]		Remarks
		Rate (lb/min)[d]	Vel[b] (fps)[e]	
7.1	1.3	14.5	4.65	System clogged at tee, orifice and venturi. Recorder pen pegged at 10 div.
7.4	5.0	15.2	4.85	Low pressure side of diff. press. cell accumulating M-1 in its line.
7.3	10.0	15.0	4.80	Accumulating M-1 in line on low pressure side of diff. press. cell.
7.4	15.8	15.2	4.85	Inlet side of venturi clogged. Recorder pen pegged at 10 div.
7.4	17.3	15.2	4.85	Nozzle clogged. Recorder pen pegged.
7.3	19.5	15.0	4.80	Inlet side of venturi clogged. Recorder pen pegged.
7.2	23.7	14.6	4.70	Inlet side of venturi clogged. Recorder pen pegged.
7.3	25.0	15.0	4.80	Stable flow.
7.3	27.0	15.0	4.80	Flow pulsed to 8.7 div. for 5 sec then returned to 7.3 div.
7.1	30.0	14.5	4.65	Flow stable
7.0	35.0	14.2	4.55	Flow stable

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[a] Values taken off plot shown in Fig 20.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 9

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% M-1 (cont)

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a] Rate (lb/min)[d]	Flow Parameters[a] Vel[b] (fps)[e]	Remarks
6.9	41.0	14.0	4.50	Purged diff. press. lines during run caused clogging at venturi.
7.5	44.1	15.3	4.95	Venturi clogged. Recorder pen pegged.
7.3	45.1	15.0	4.80	Venturi clogged. Recorder pen pegged.
7.4	50.0	15.2	4.85	Flow stable
7.3	54.5	15.0	4.80	Nozzle clogged. Recorder pen pegged.
7.4	56.8	15.2	4.85	End of test. Clogging of venturi and nozzle a major problem with the M-1 used on this program.

---

[a] Values taken off plot shown in Fig 20.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.

Table 10

Results of long duration aqueous, explosive slurry flow test

Slurry composition: 25% HMX

Recorder Reading (0-10 div)[c]	Elapsed Time (min)	Flow Parameters[a] Rate (lb/min)[d]	Flow Parameters[a] Vel[b] (fps)[e]	Remarks
7.2	1.0	15.5	4.70	No problems.
7.5	5.0	16.2	4.90	No problems.
7.5	10.0	16.2	4.90	No problems.
7.5	15.0	16.2	4.90	Flow stable.
7.5	20.0	16.2	4.90	No problems.
7.5	25.0	16.2	4.90	No problems.
7.5	30.0	16.2	4.90	No problems.
7.5	35.0	16.2	4.90	Flow stable.
7.5	40.0	16.2	4.90	No problems.
7.5	45.0	16.2	4.90	Flow stable.
7.5	50.0	16.2	4.90	No problems.
7.5	55.0	16.2	4.90	Flow stable throughout entire test. No clogging problems of any kind. End of test.

---

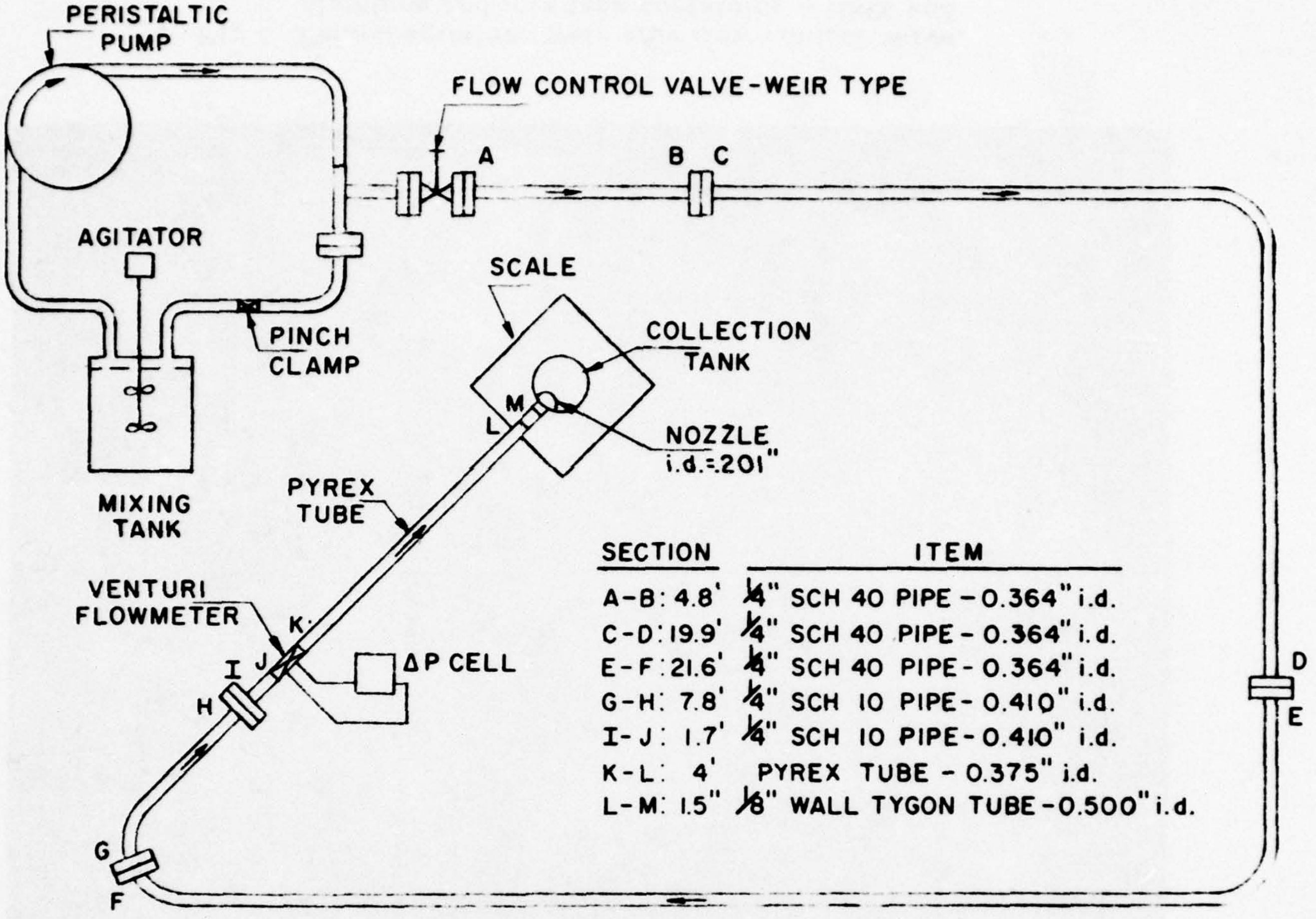
[a] Values taken off plot shown in Fig 23.

[b] Slurry vel in 3/8 in. i.d. glass pipe, calculated using theoretical density at 25% solids concentration.

[c] See calibration curve, Fig 7.

[d] To convert from lb/min to kg/sec multiply by 7.559873×10^{-3}.

[e] To convert from fps to m/sec multiply by 3.048×10^{-1}.



SECTION	ITEM
A-B: 4.8'	1/4" SCH 40 PIPE - 0.364" i.d.
C-D: 19.9'	1/4" SCH 40 PIPE - 0.364" i.d.
E-F: 21.6'	1/4" SCH 40 PIPE - 0.364" i.d.
G-H: 7.8'	1/4" SCH 10 PIPE - 0.410" i.d.
I-J: 1.7'	1/4" SCH 10 PIPE - 0.410" i.d.
K-L: 4'	PYREX TUBE - 0.375" i.d.
L-M: 1.5"	1/8" WALL TYGON TUBE - 0.500" i.d.

Fig 1 Simulated aqueous, explosive slurry flow system-Picatinny Arsenal incinerator

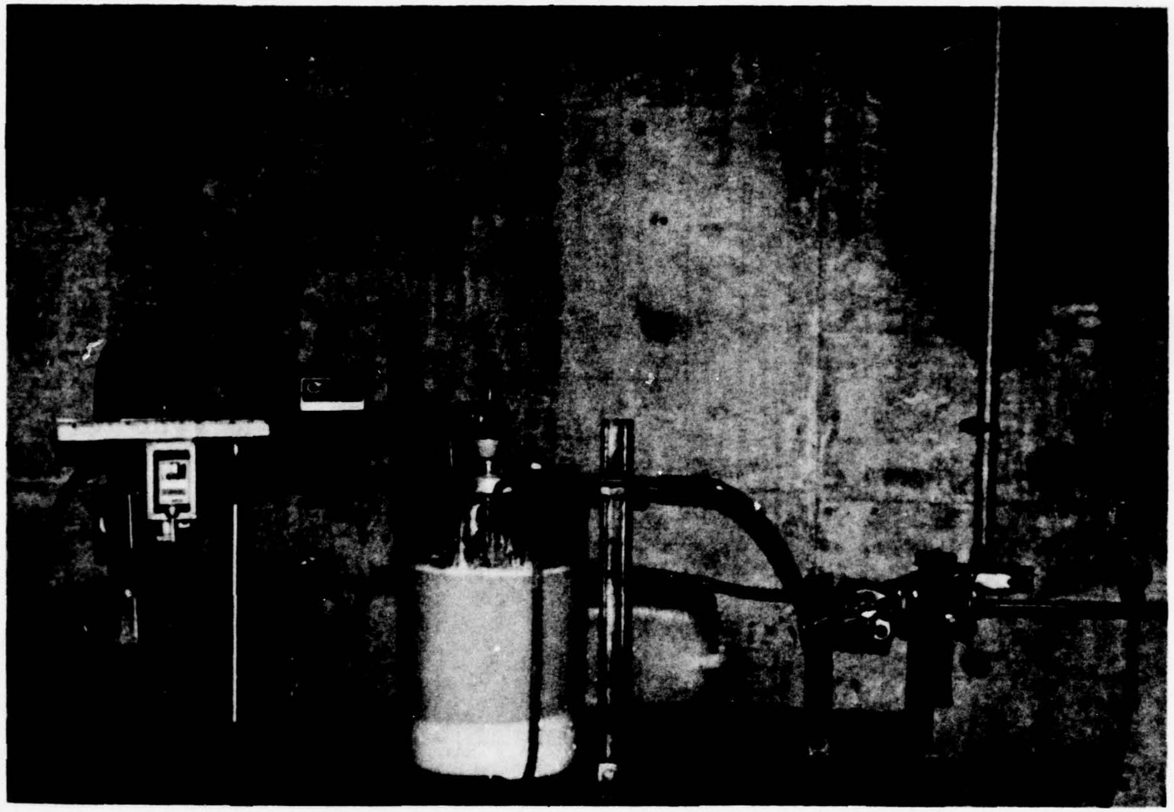


Fig 2 Pump, agitator, weir type flow control valve, plumbing and mix tank containing a HMX and water slurry

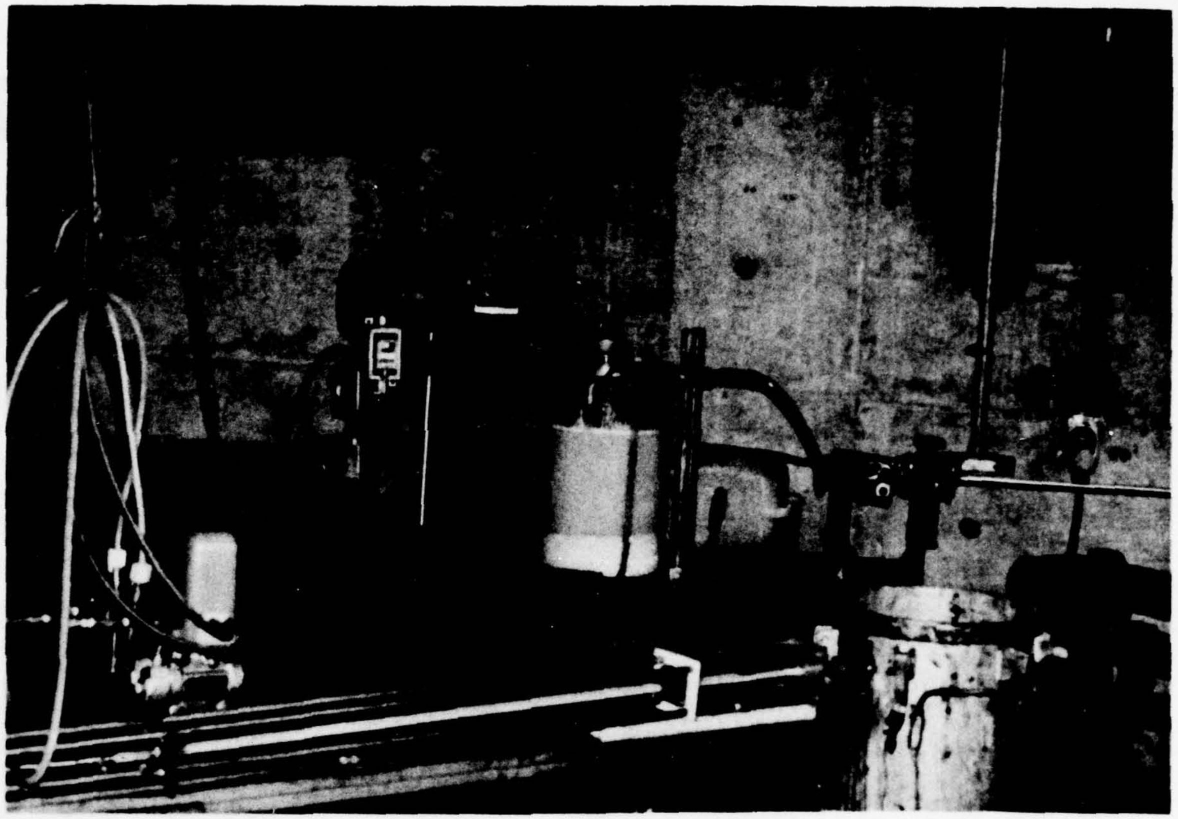


Fig 3 Slurry collection tank on scale with venturi flowmeter, differential pressure transmitter and glass pipe in the foreground

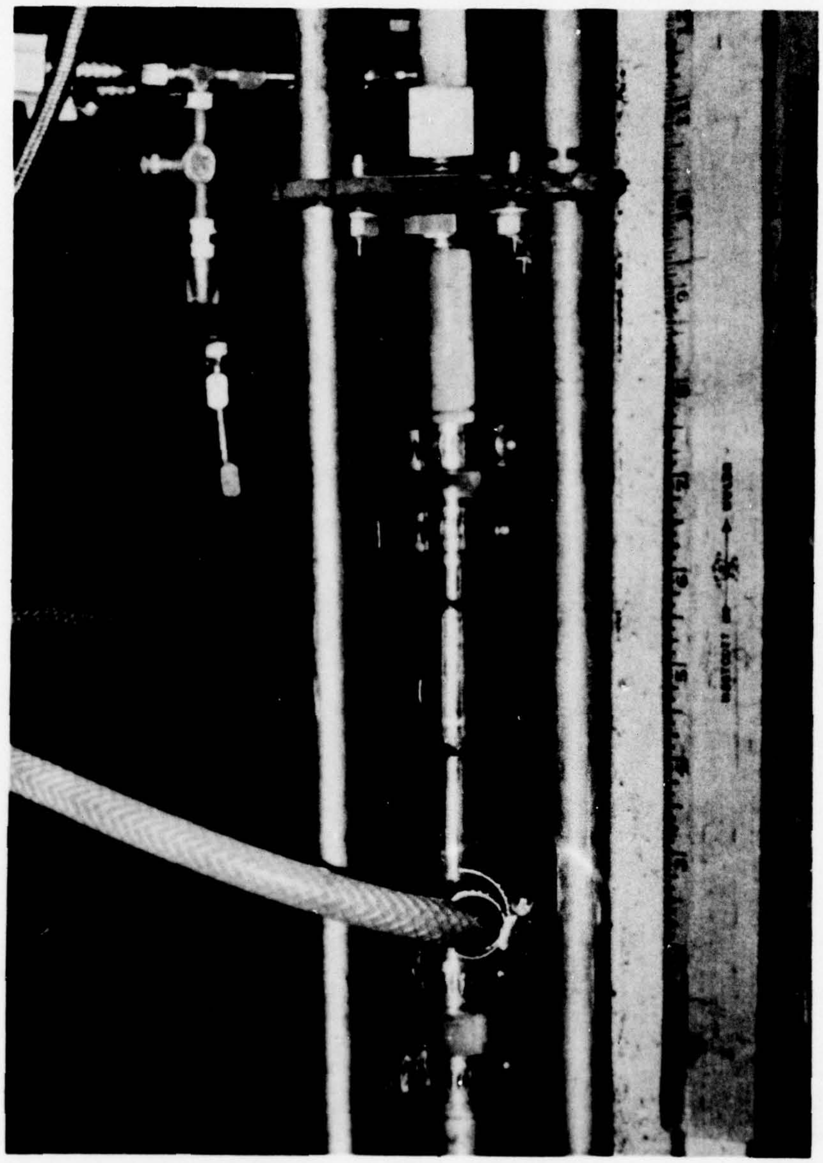


Fig 4 Venturi flowmeter with water filled pressure transmitting lines at its inlet and throat

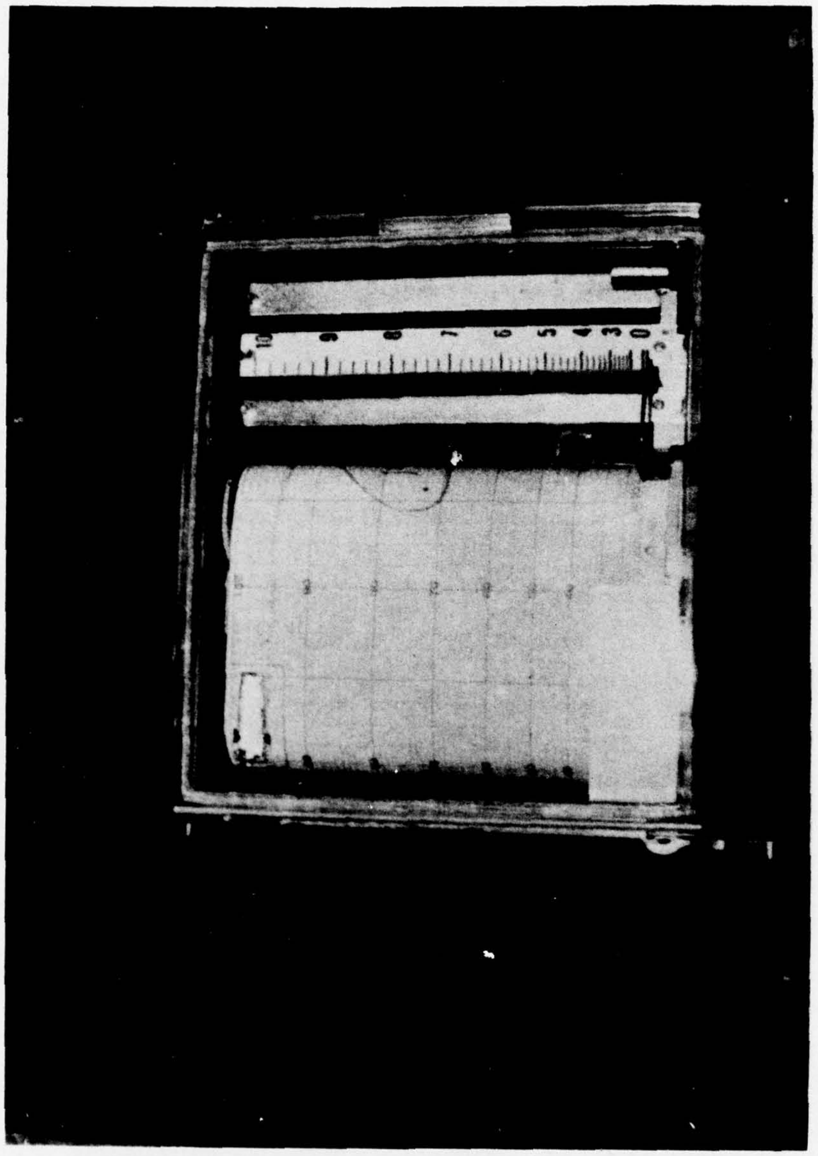


Fig 5 Pneumatically actuated recorder

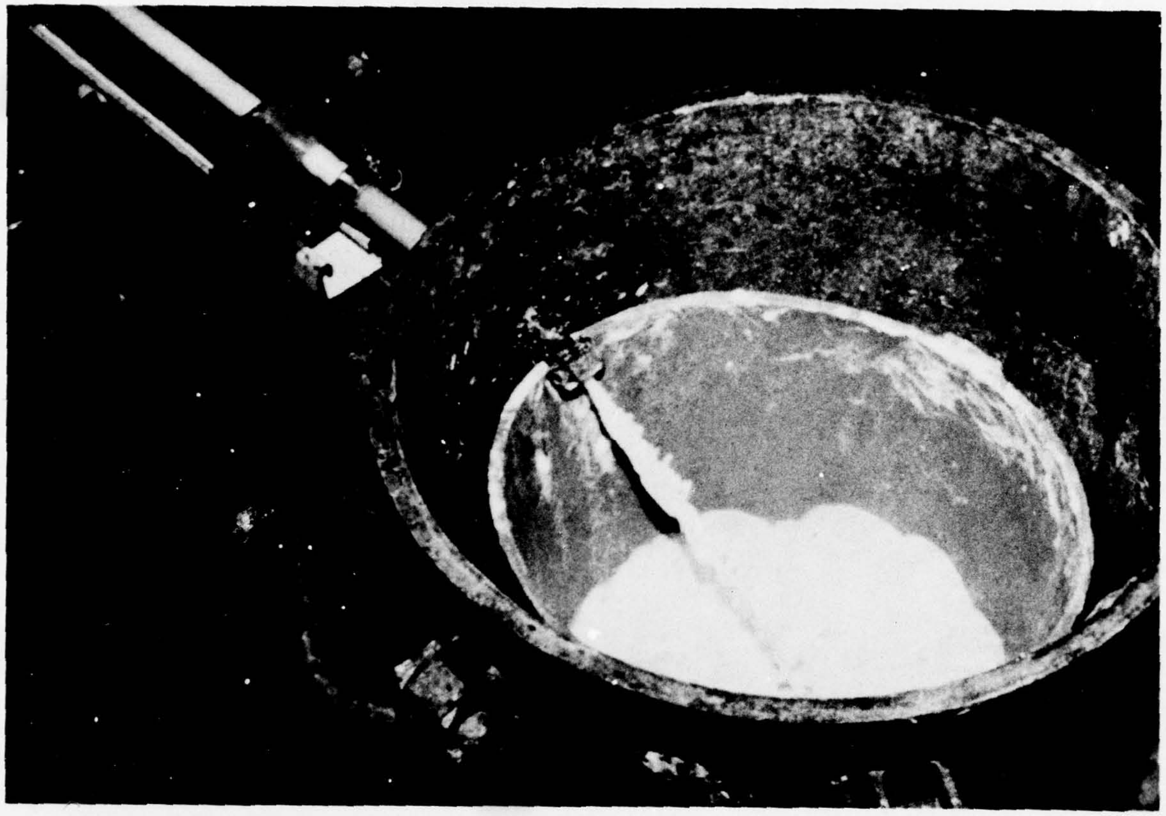


Fig 6 Nozzle injecting an aqueous, HMX slurry into a collection tank during a flow rate test

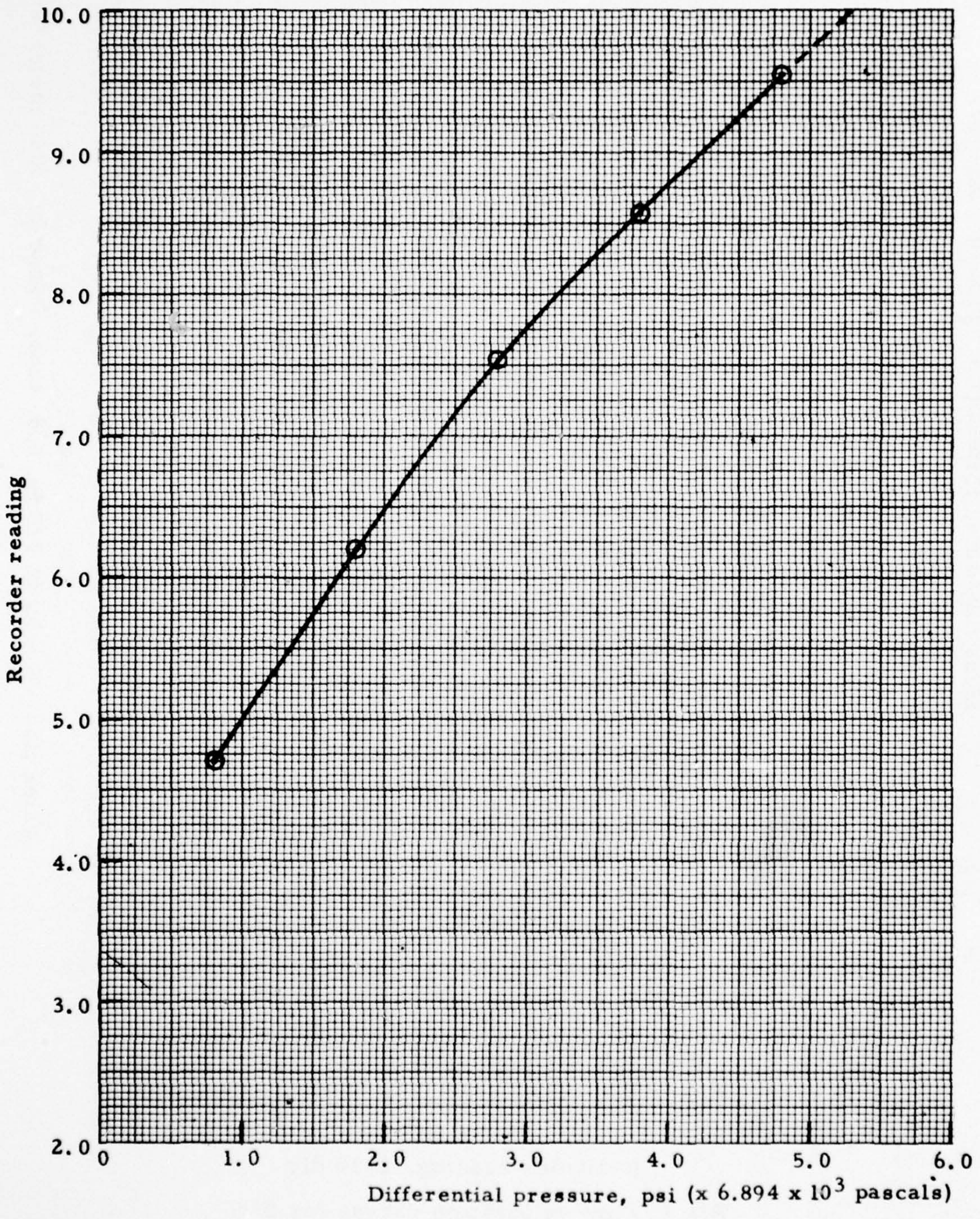


Fig 7 Calibration curve for differential pressure cell

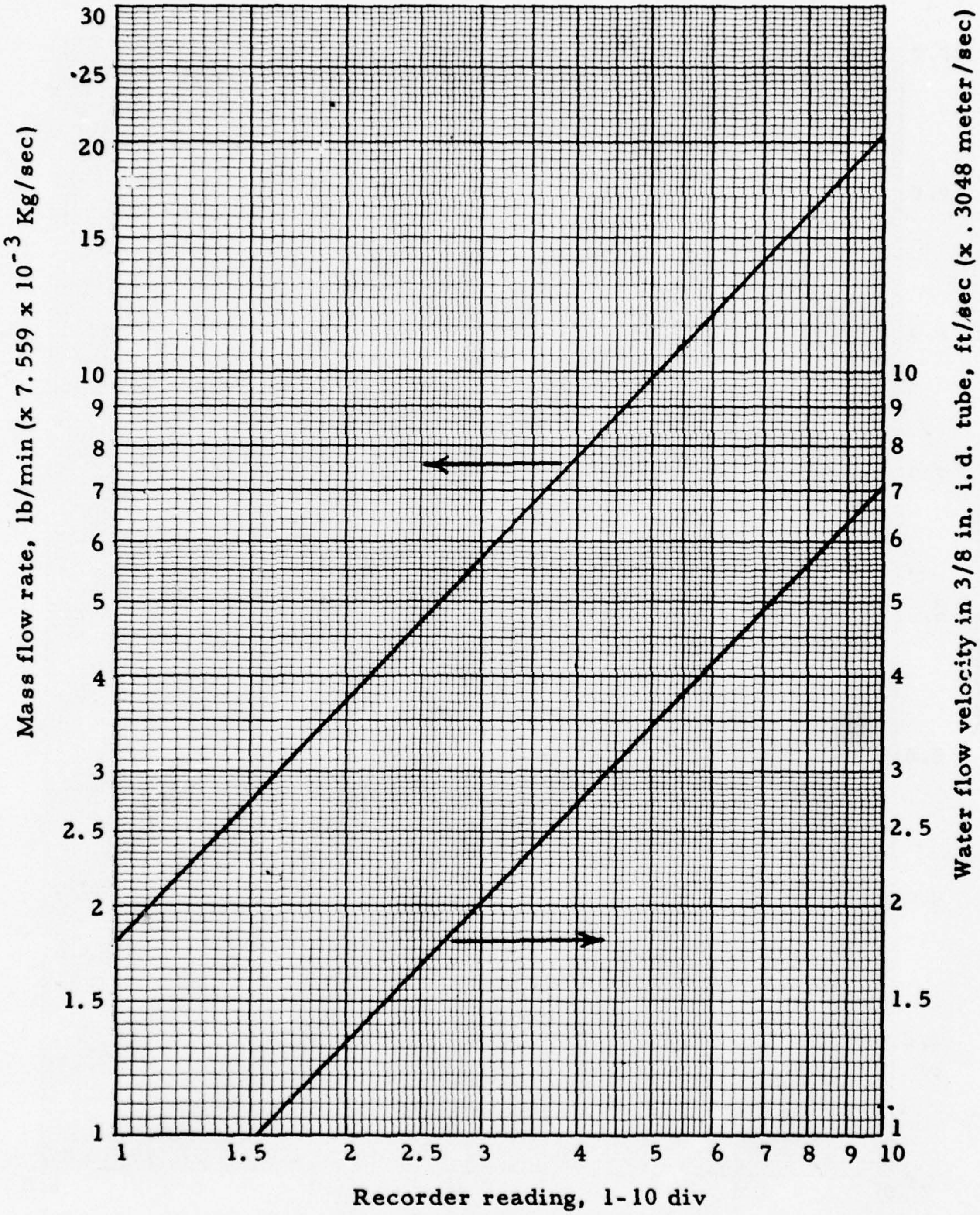


Fig 8 Flow calibration curves for S/N 611647-1 venturi flowmeter

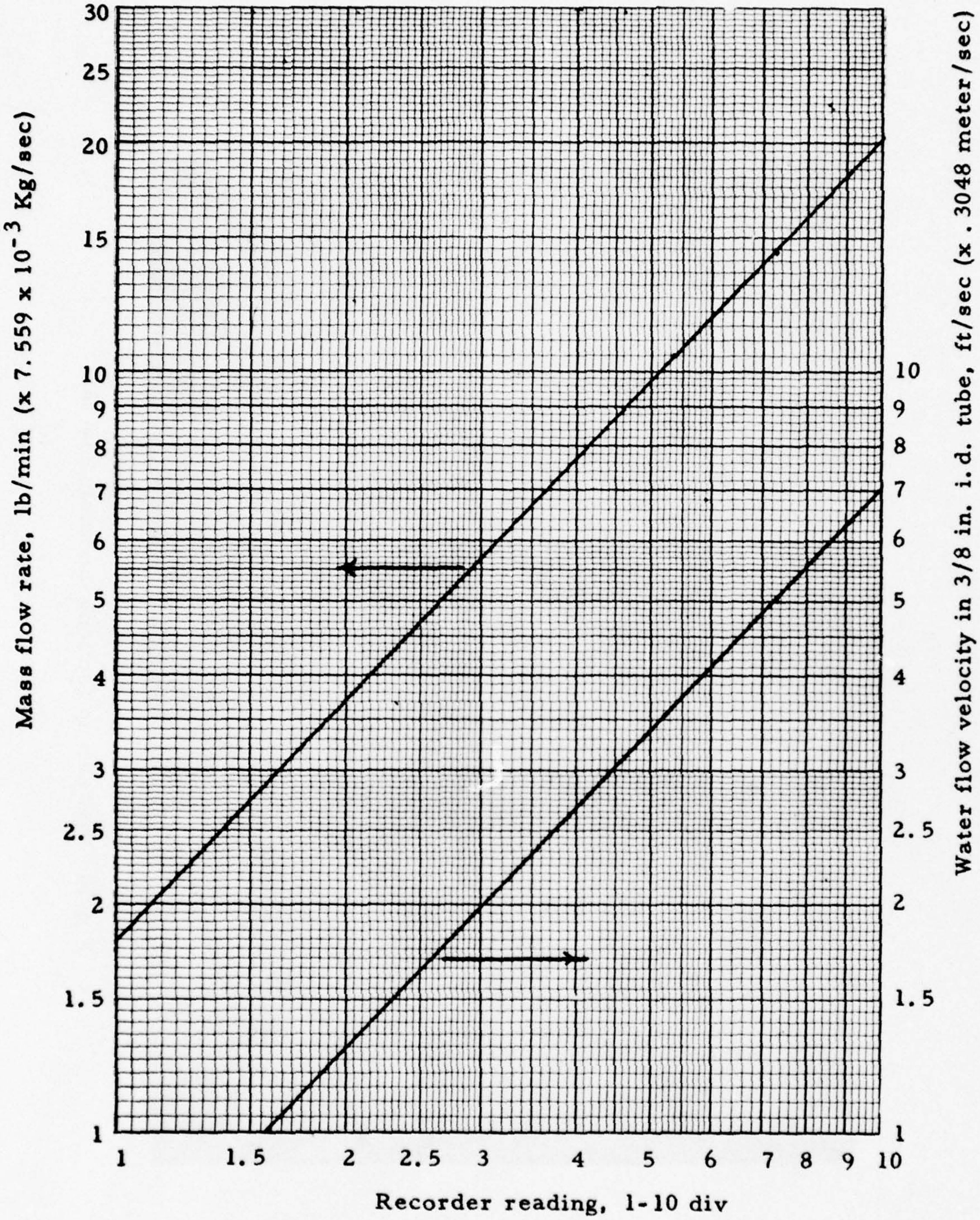


Fig 9 Flow calibration curves for S/N 611647-2 venturi flowmeter

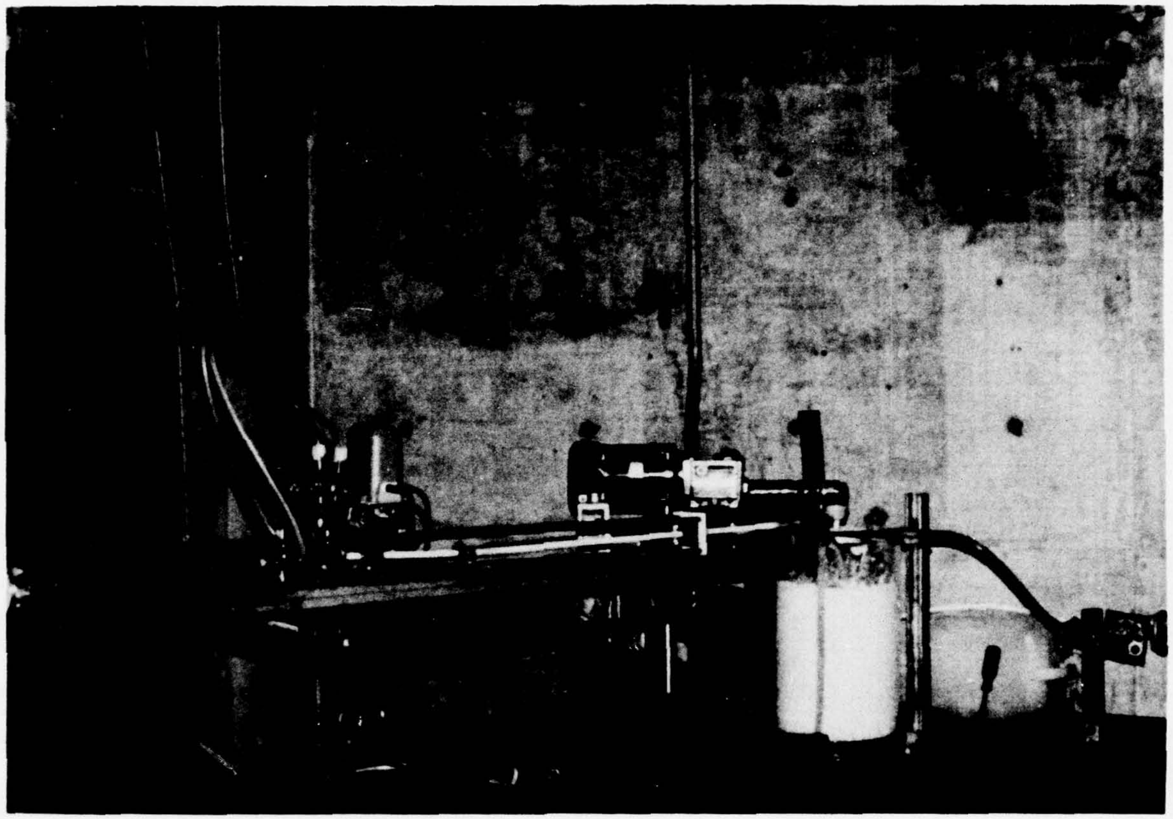


Fig 10 Test set-up for long duration flow test

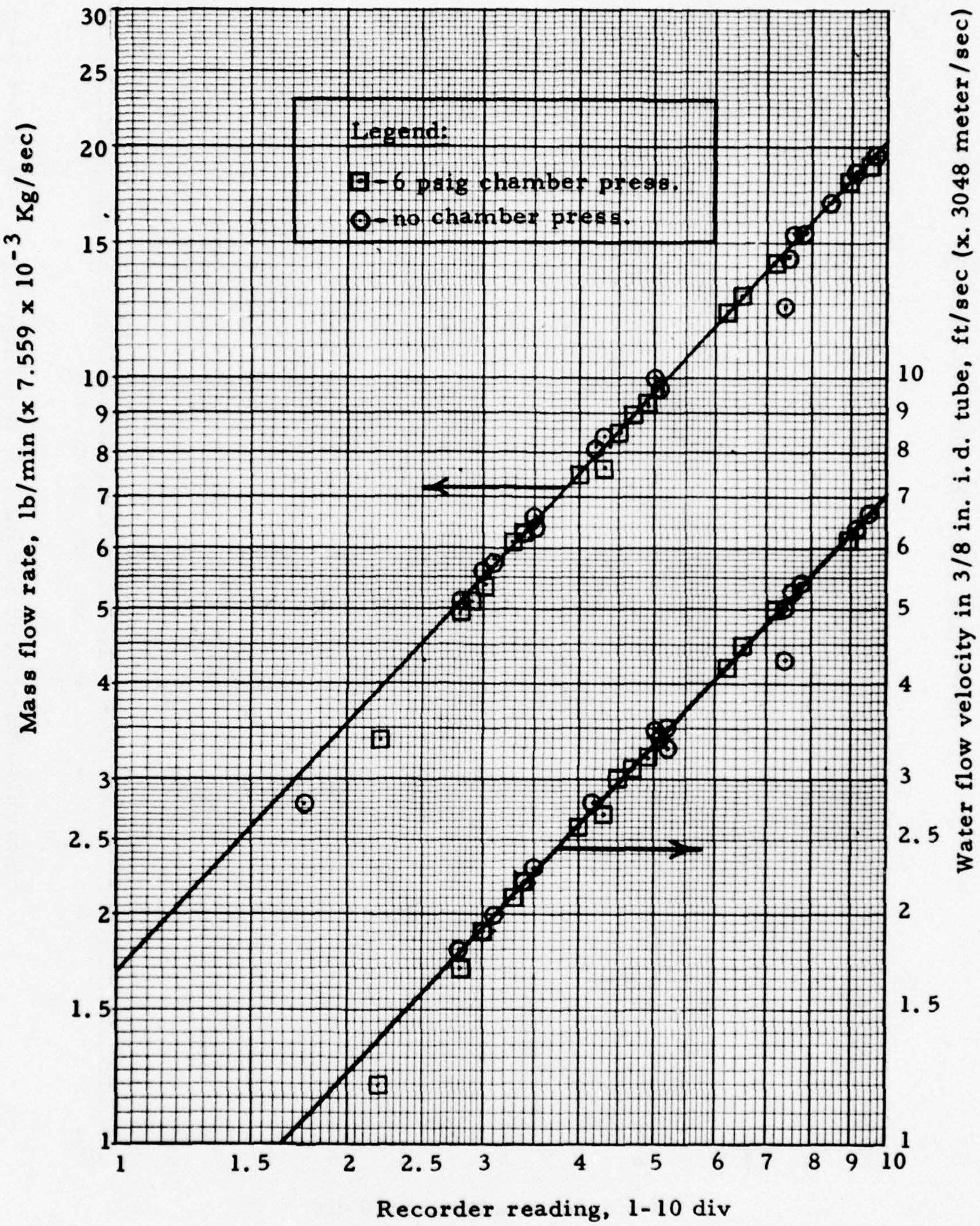


Fig 11 Effect of simulated combustion chamber pressure on fluid flow parameters

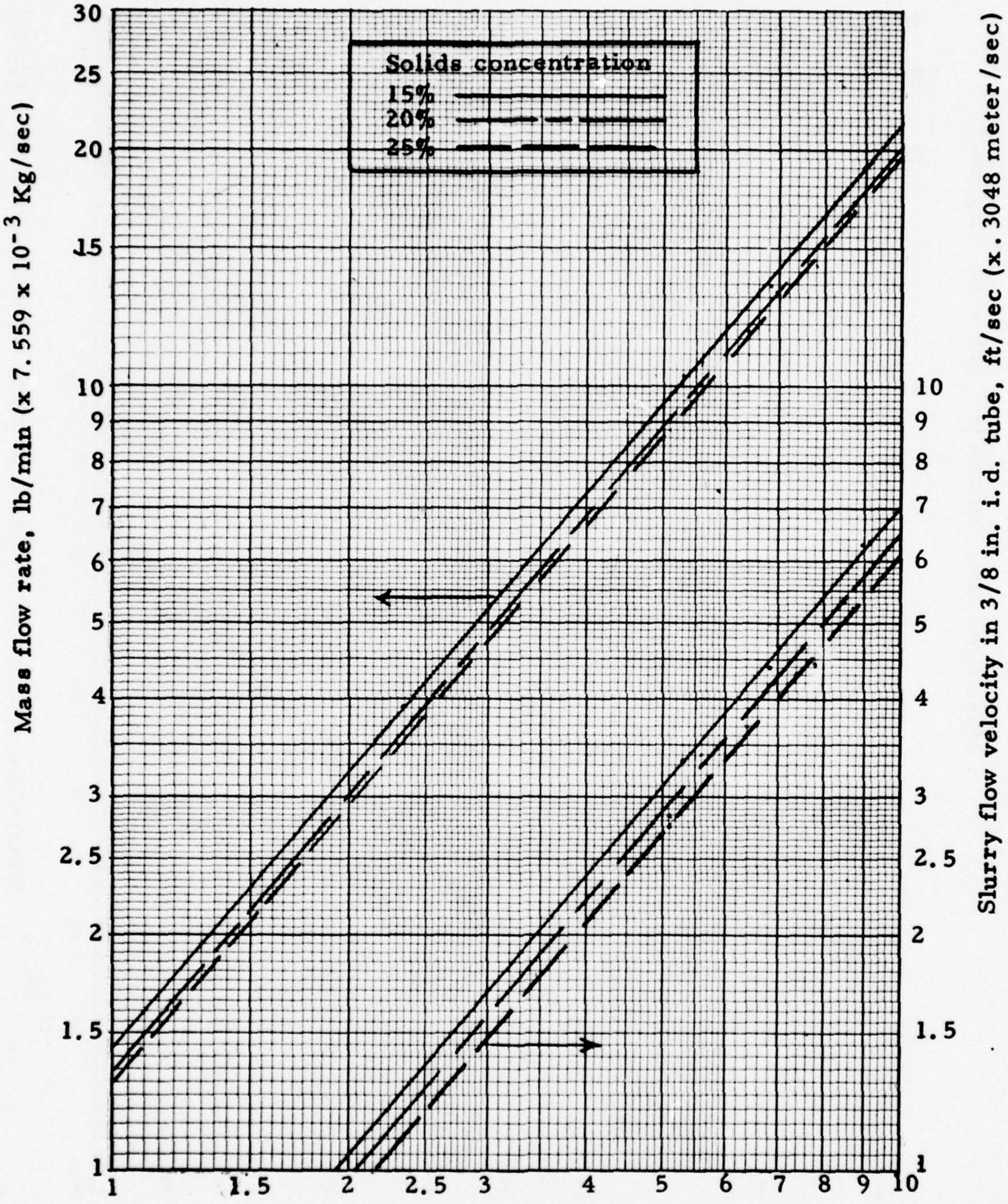


Fig 12 Mass flow rate and velocity curves for aqueous, TNT slurries, test series I

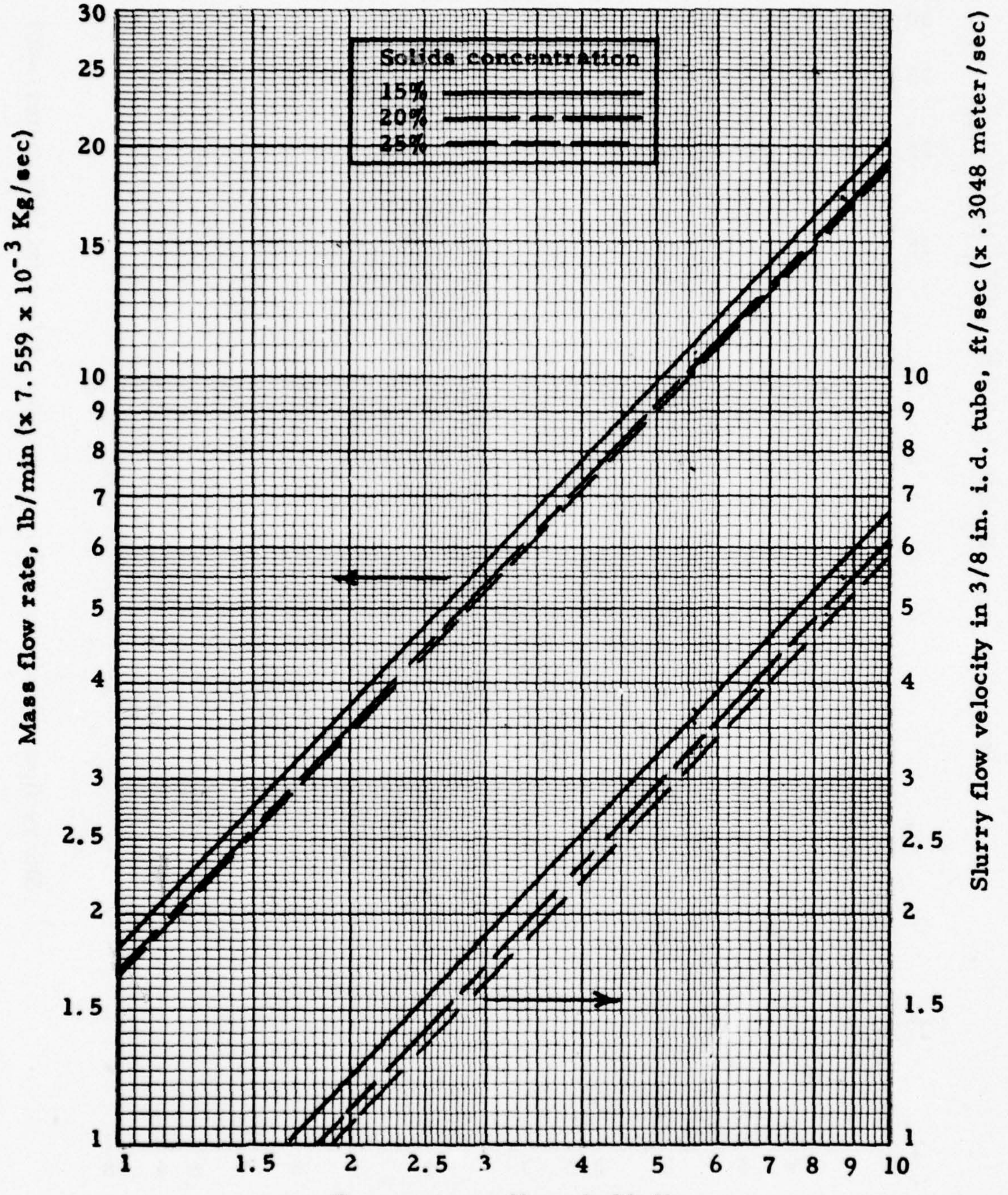


Fig 13 Mass flow rate and velocity curves for aqueous, TNT slurries, test series II

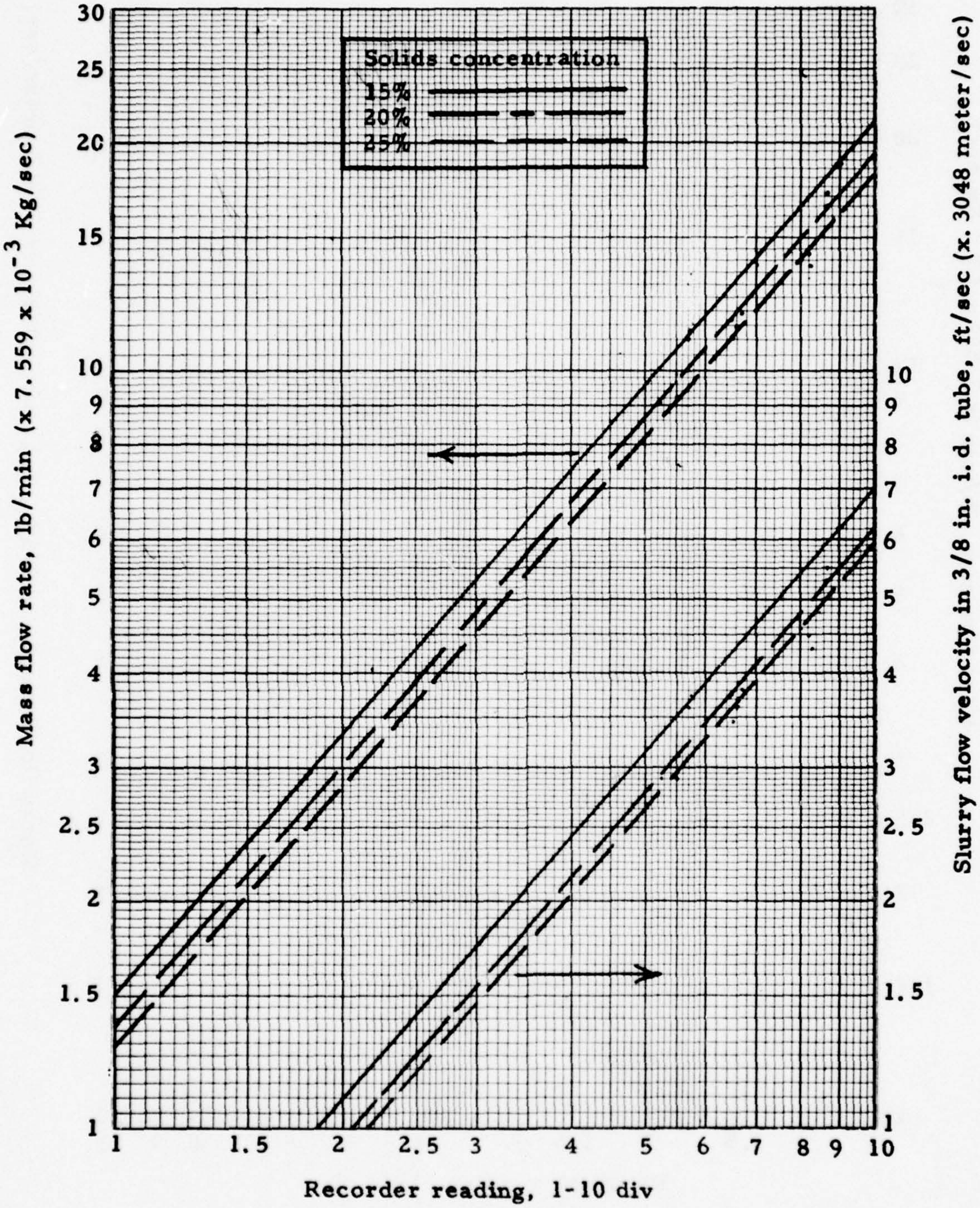


Fig 14 Mass flow rate and velocity curves for aqueous, TNT slurries, test series III

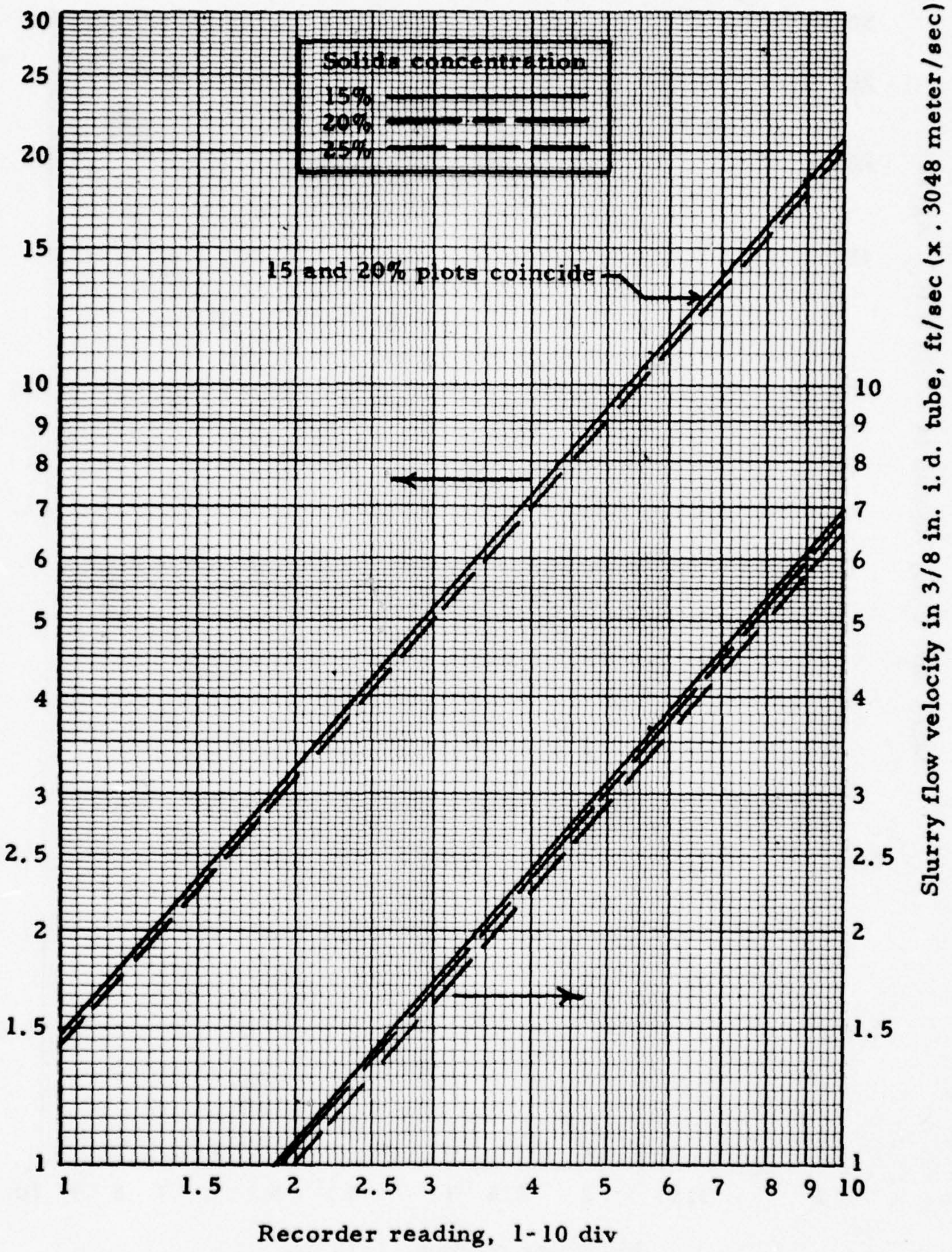


Fig 15 Mass flow rate and velocity curves for aqueous, Comp B slurries, test series I

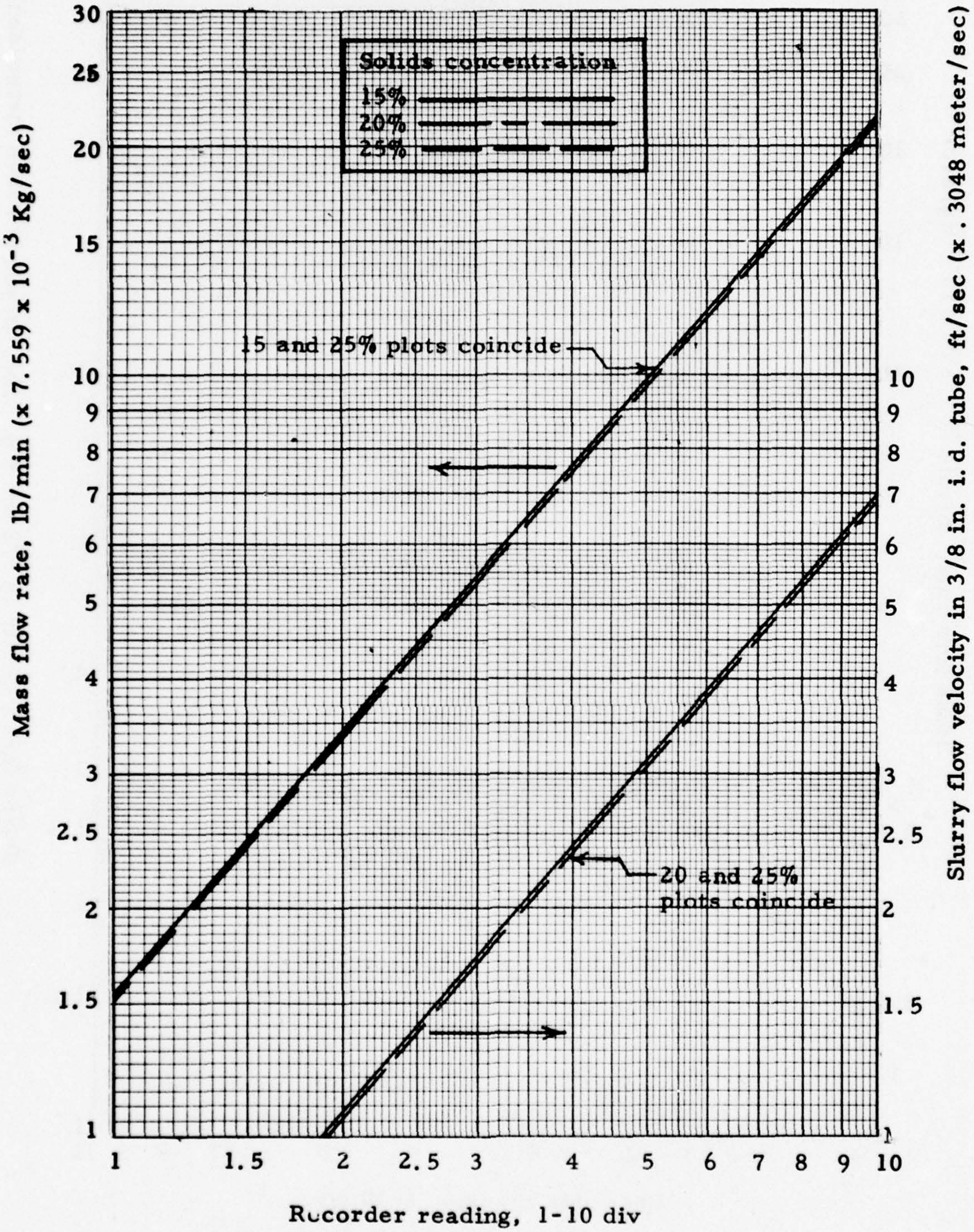


Fig 16 Mass flow rate and velocity curves for aqueous, Comp B slurries, test series II

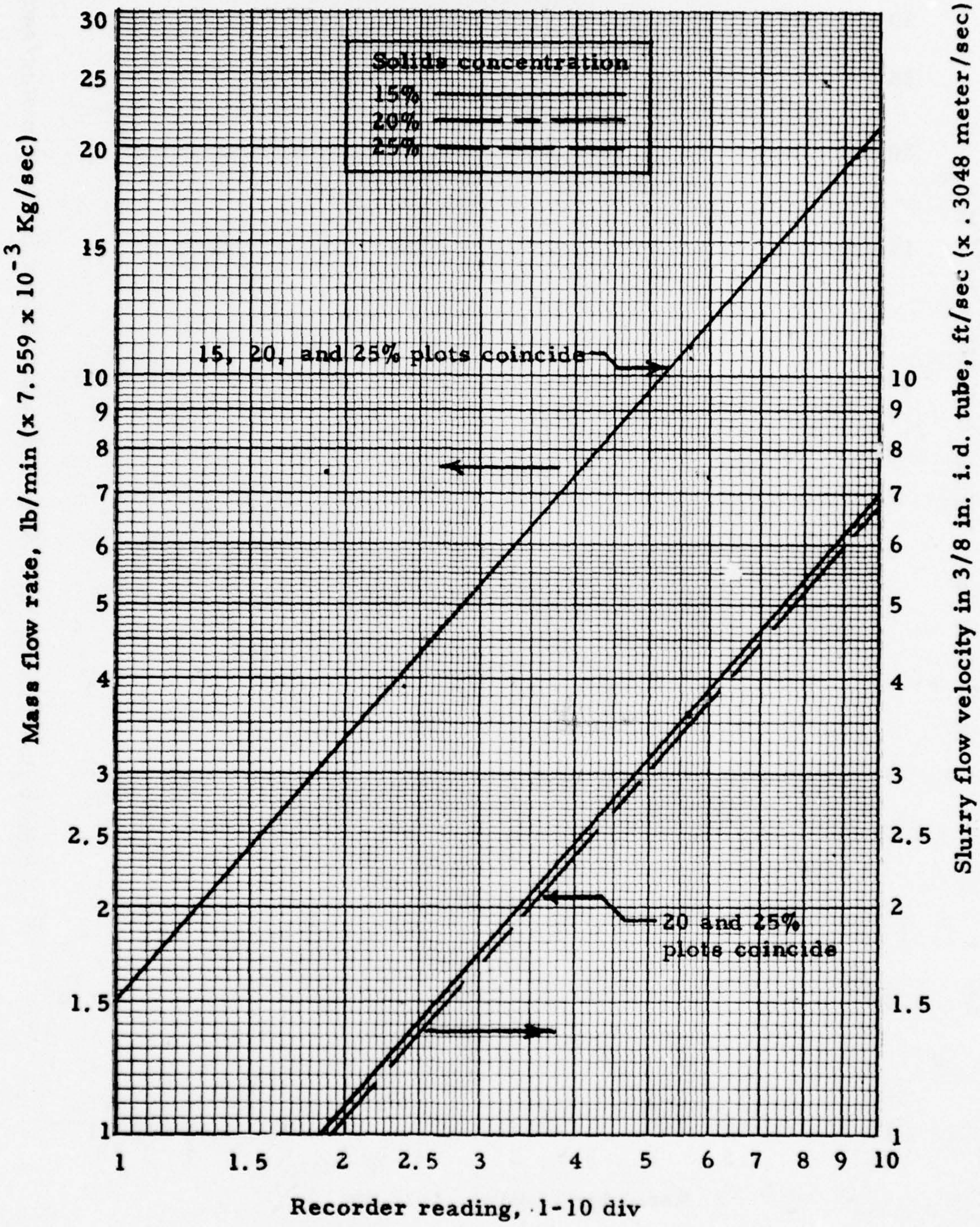


Fig 17 Mass flow rate and velocity curves for aqueous, Comp B slurries, test series III

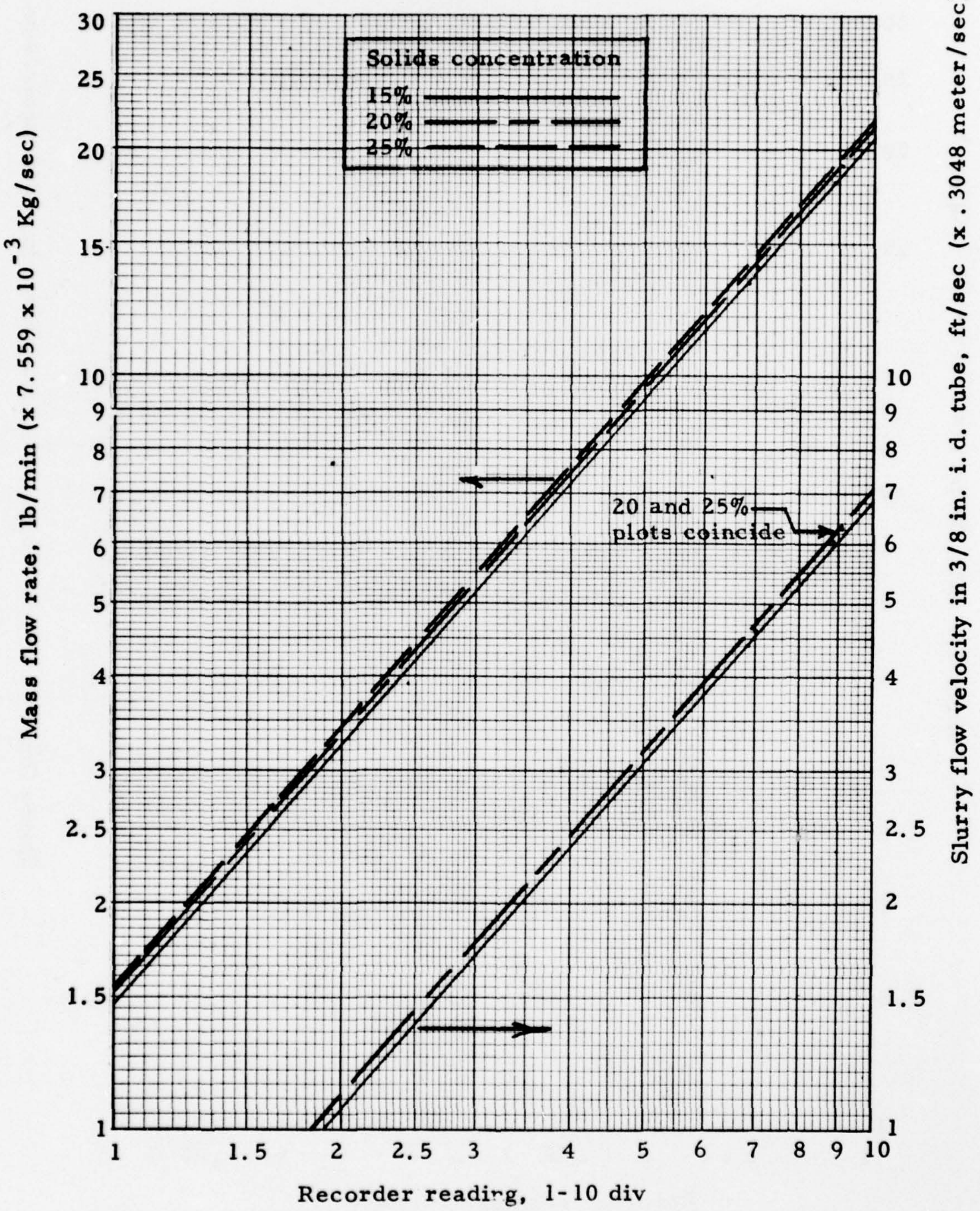


Fig 18 Mass flow rate and velocity curves for aqueous, M-1 slurries, test series I

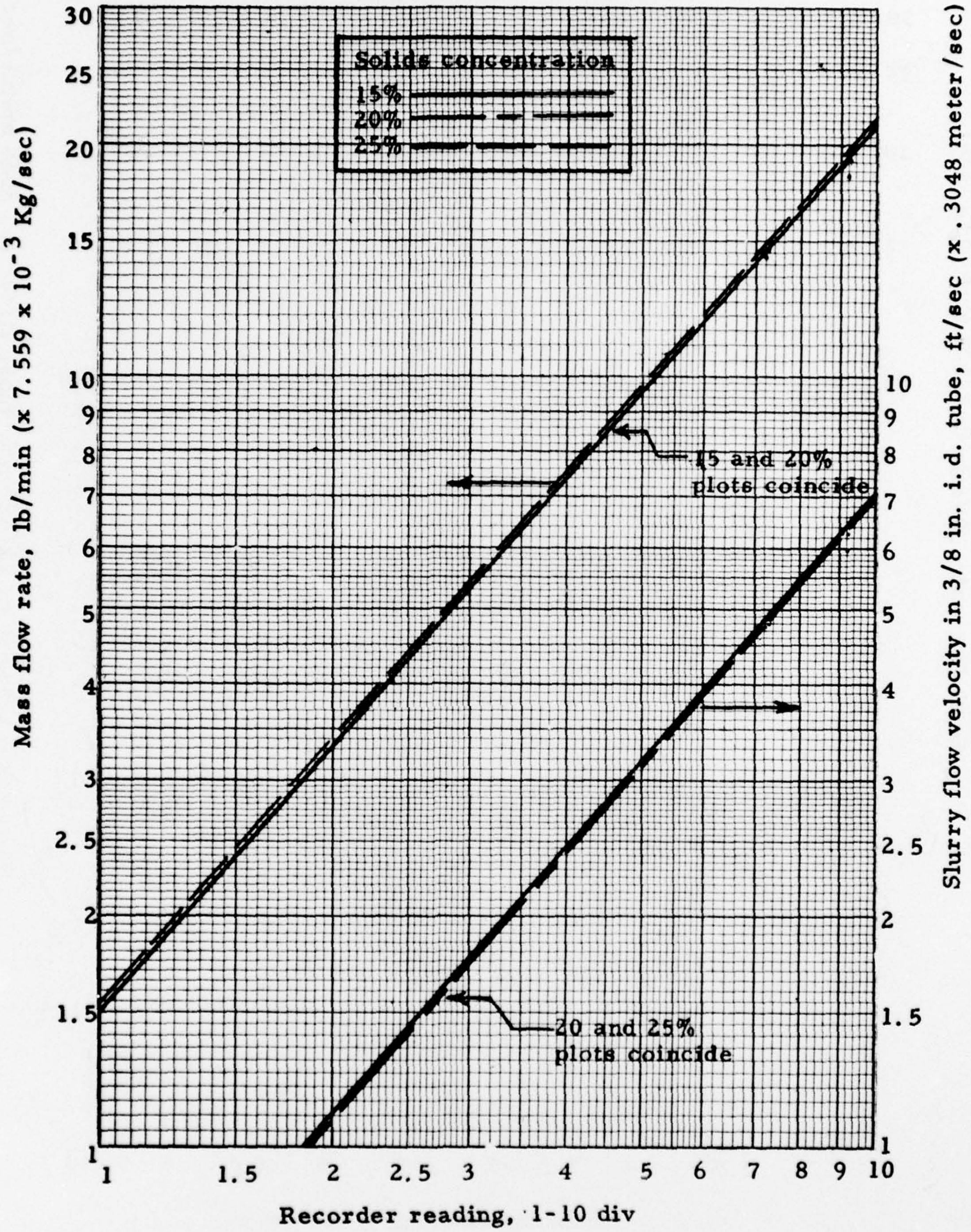


Fig 19 Mass flow rate and velocity curves for aqueous, M-1 slurries, test series II

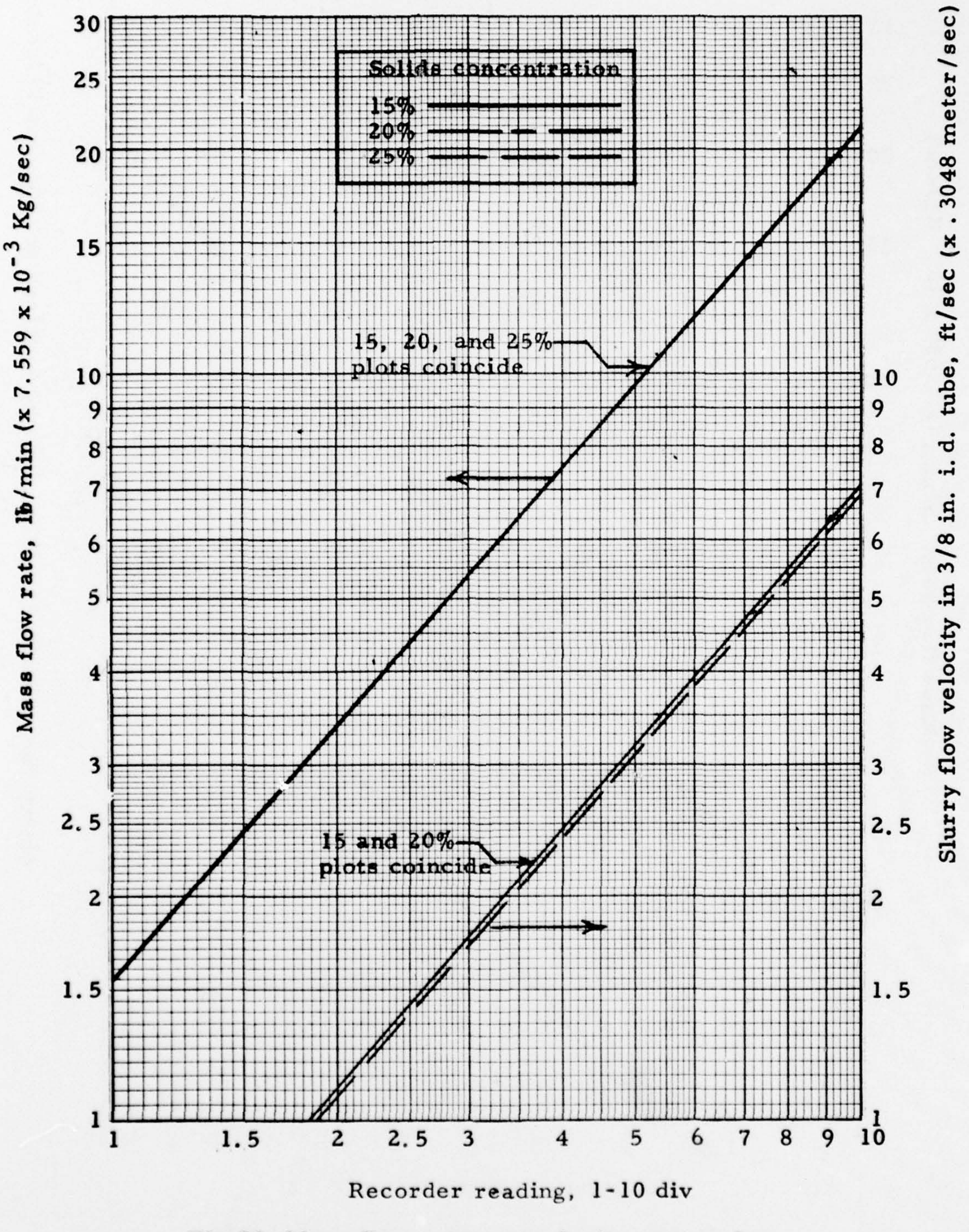


Fig 20 Mass flow rate and velocity curves for aqueous, M-1 slurries, test series III

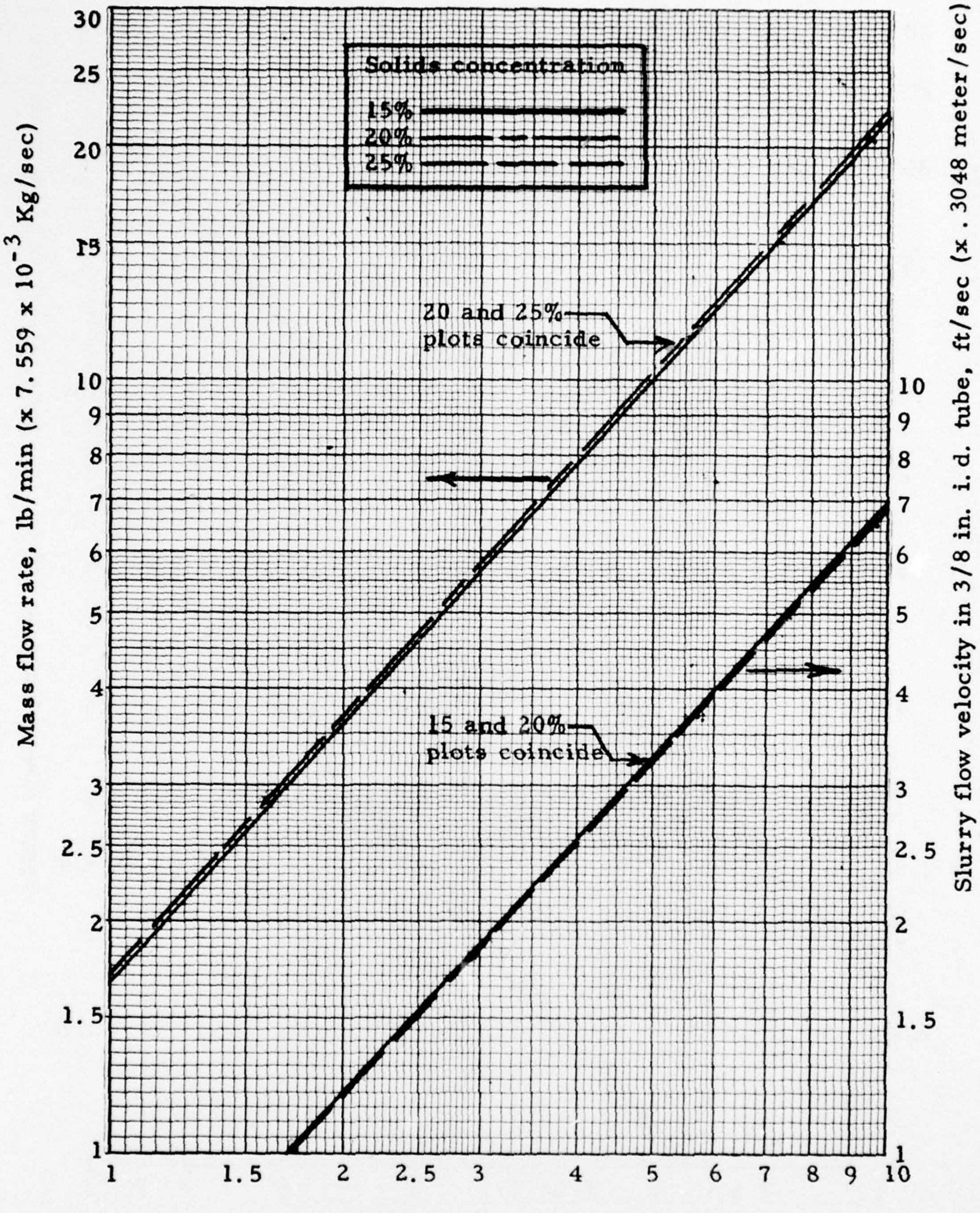


Fig 21 Mass flow rate and velocity curves for aqueous, HMX slurries, test series I

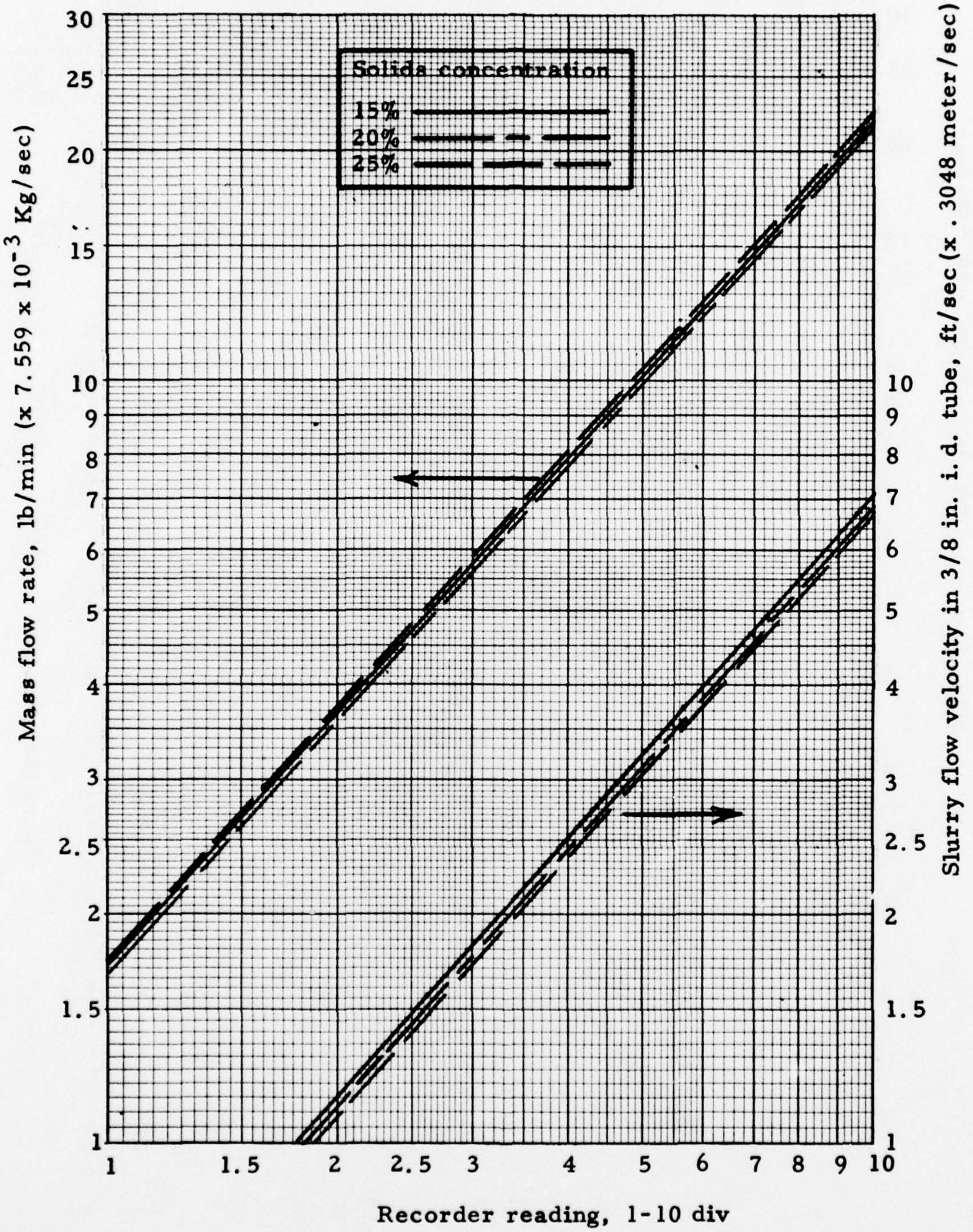


Fig 22 Mass flow rate and velocity curves for aqueous, HMX slurries test series II

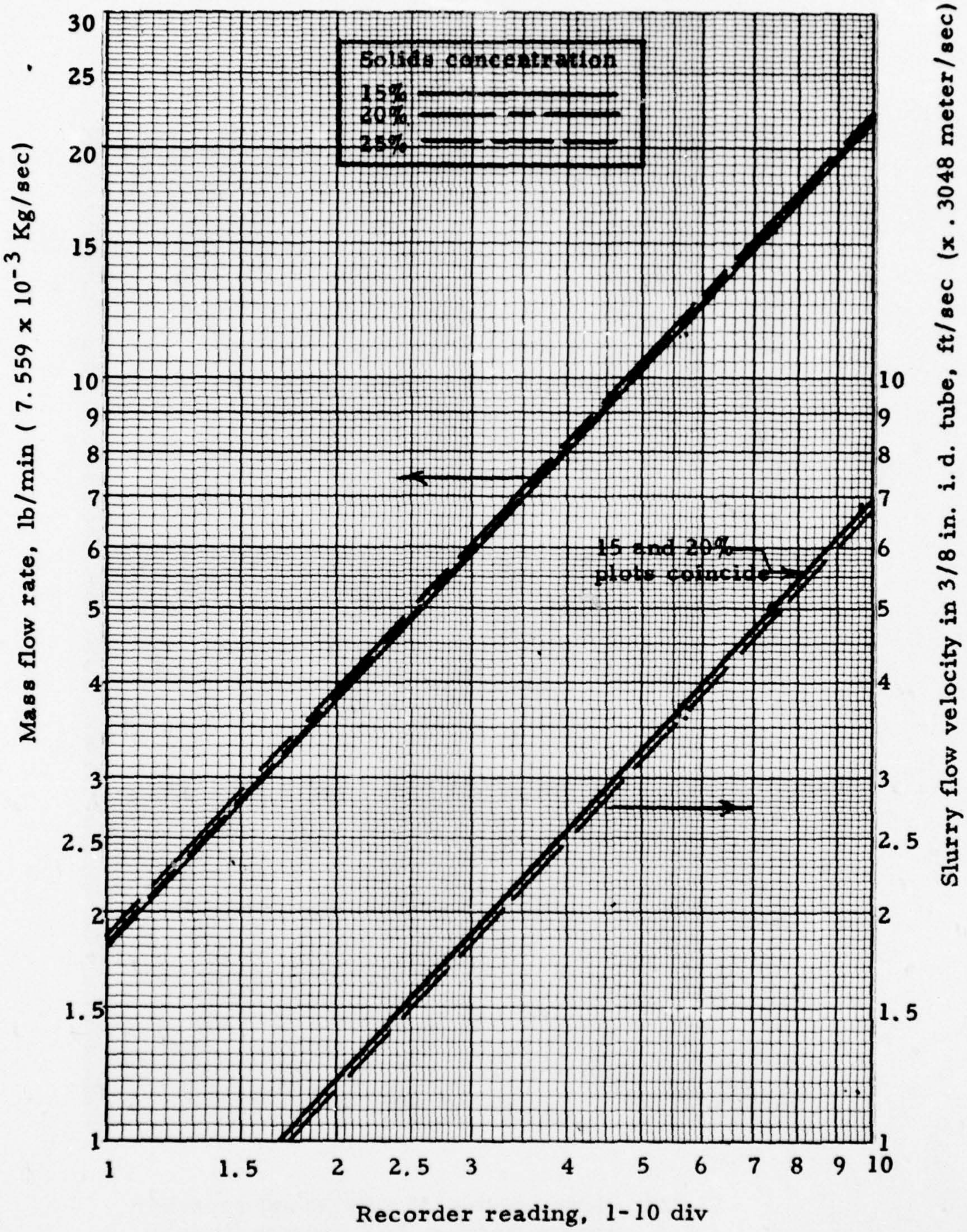


Fig 23 Mass flow rate and velocity curves for aqueous, HMX slurries, test series III

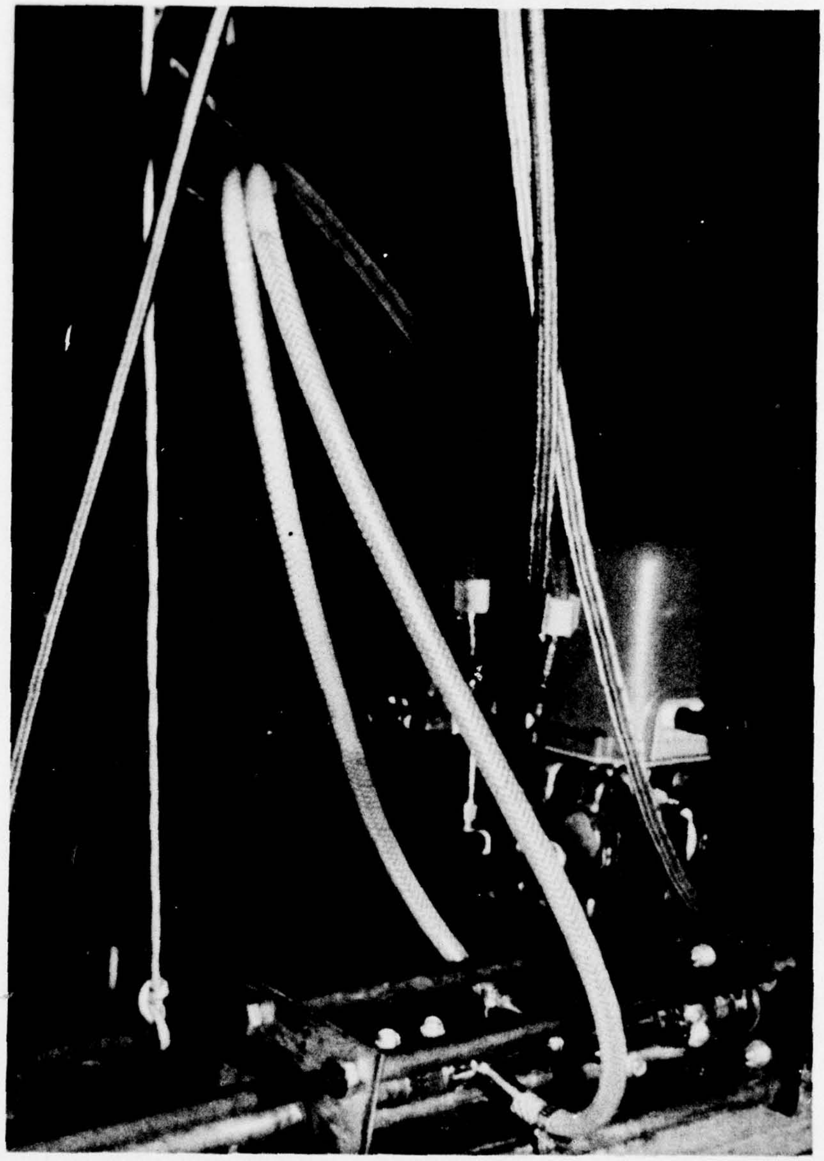


Fig 24 Close-up view of differential pressure transmitter and TNT foam in its inlet lines

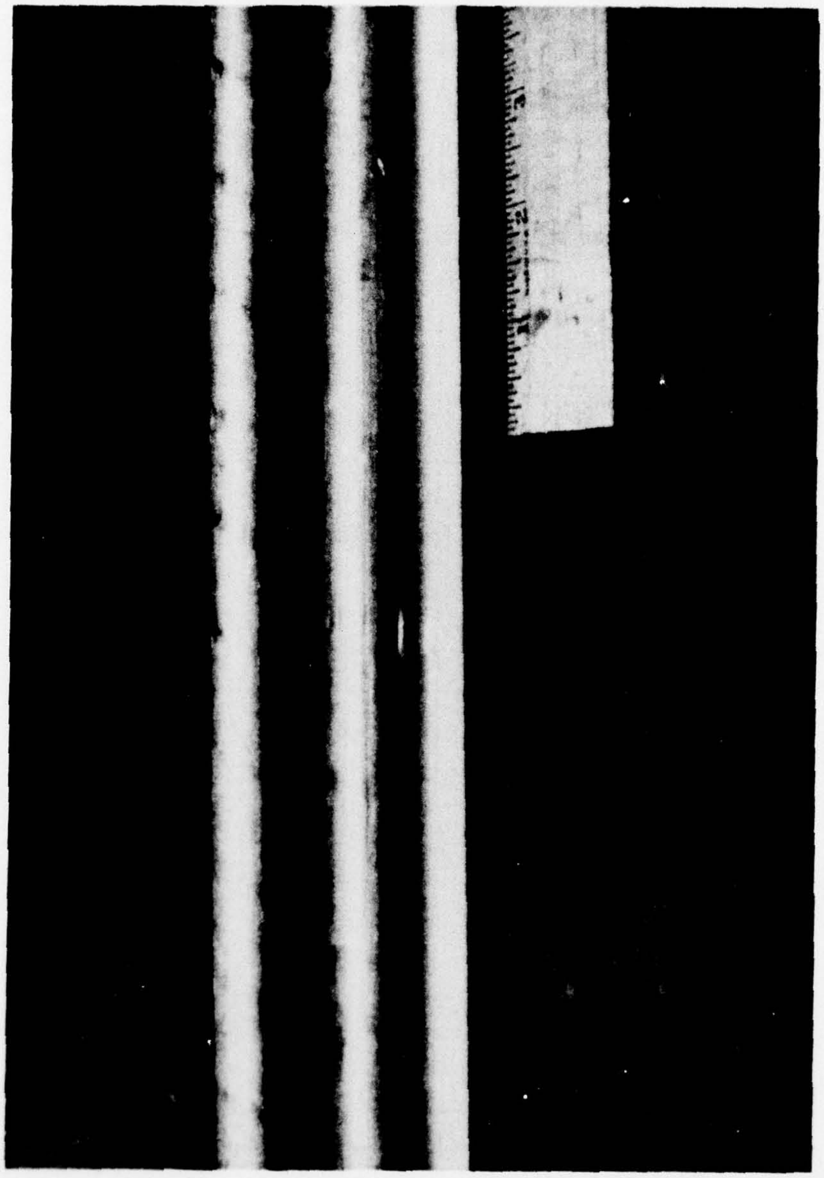


Fig 25 Aqueous, HMX slurry flowing in glass pipe

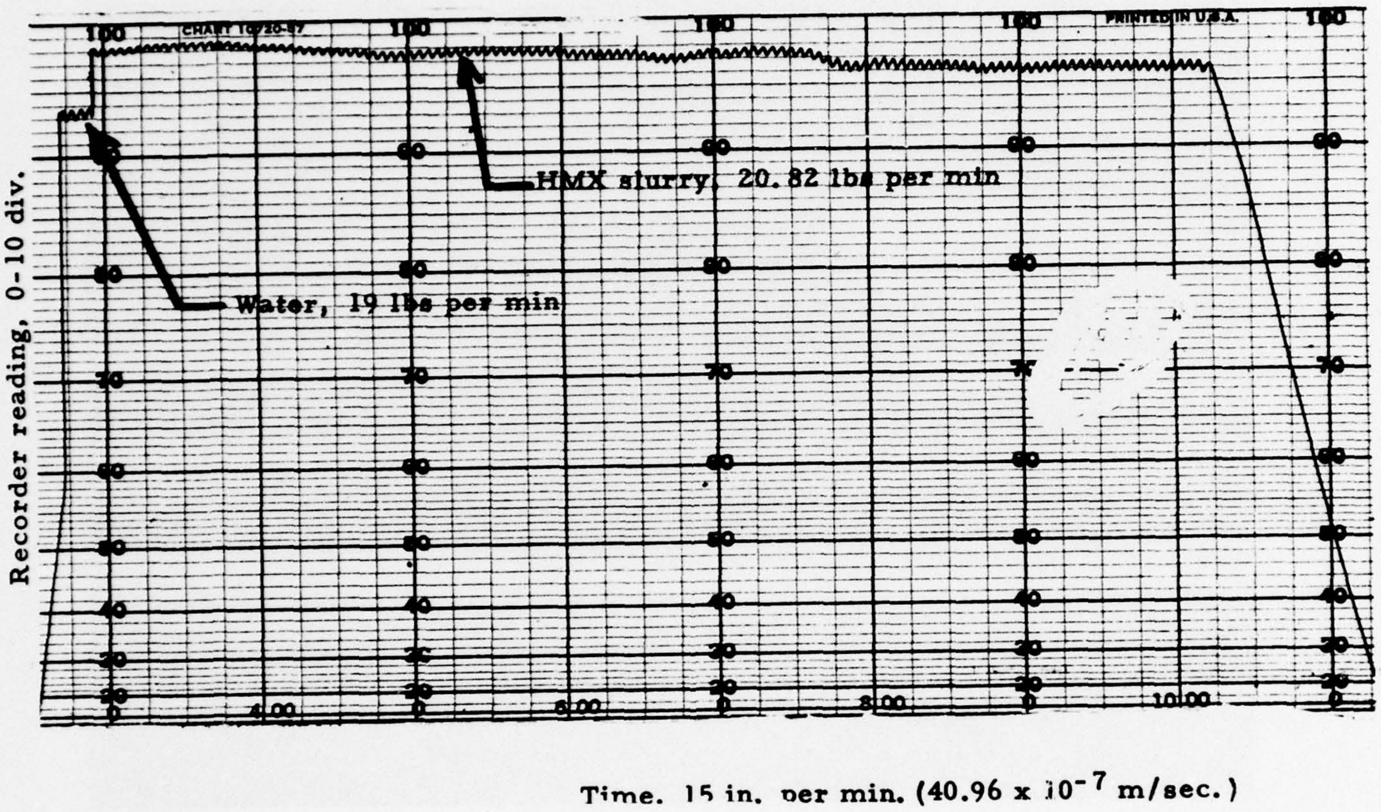


Fig 26 HMX slurry recorder trace, test no. 161

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