LIQUID FLOW BENCH

by

Group G

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Appendix G

Liquid Flow Bench Student Manual

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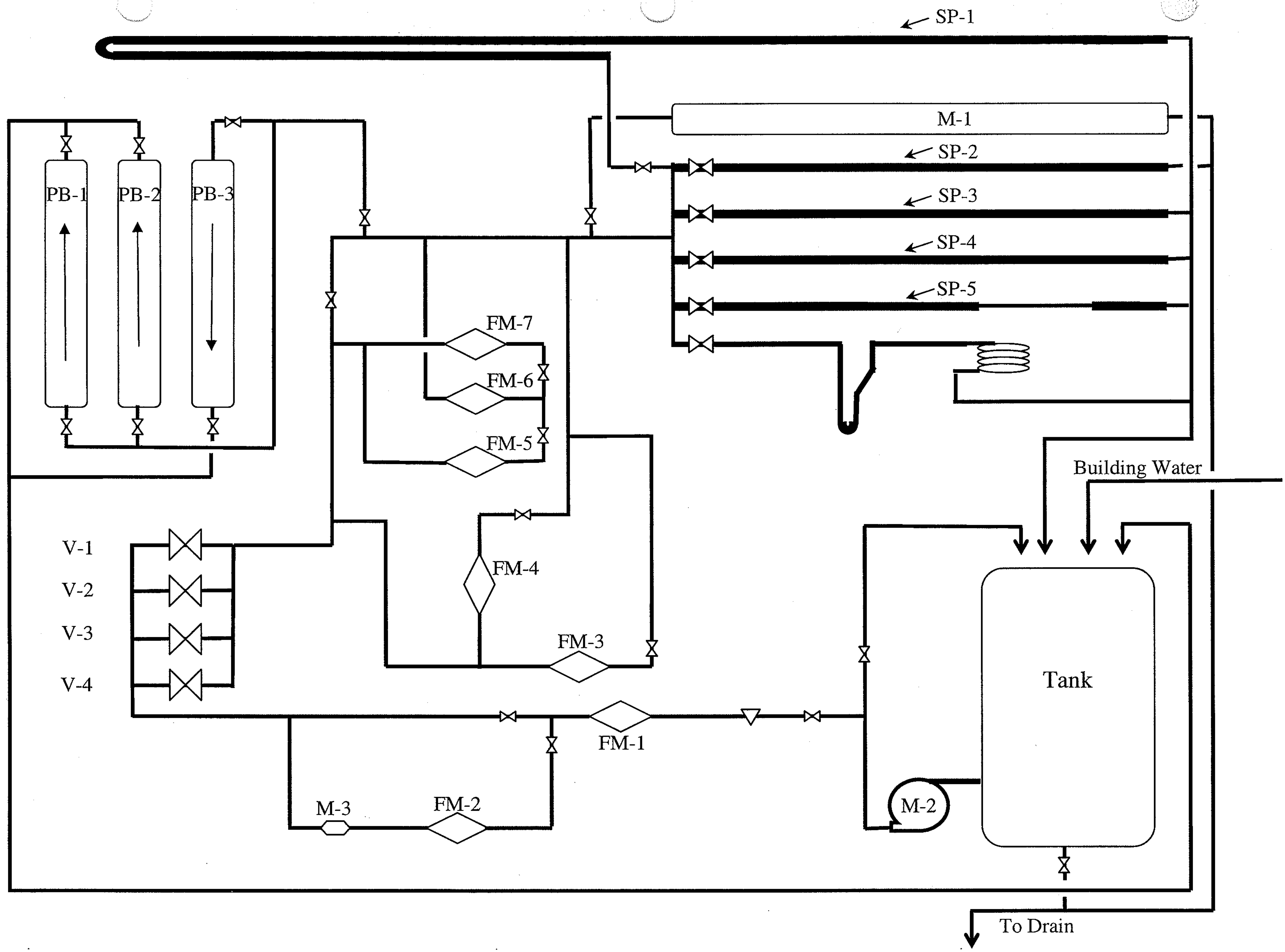

SP-1
M-1
SP-2
SP-3
SP-4
SP-5
PB-1
PB-2
PB-3
FM-7
FM-6
FM-5
FM-4
FM-3
FM-1
FM-2
M-3
M-2
V-1
V-2
V-3
V-4
Building Water
Tank
To Drain

Equipment Items

Item from flowsheet	Description	Status
FM-1	V-cone Flowmeter	Calibrated
FM-2	Disk Totalizer	Calibrated
FM-3	Minimag Flowmeter	Calibrated
FM-4	Rotameter	Working
FM-5	Venturi Flowmeter	Calibrated
FM-6		Working/Needs Better Strobe Light
FM-7	Orifice Flowmeter	Calibrated
M-1	Glass Site Tube/Dye; Laminar/Turbulent Demo	Functional
M-2	Pump	Functional
M-3	Turbine	Non-Functional
PB-1	Packed Bed – Glass Beads	Functional
PB-2	Packed Bed – Catalyst Pellets	Functional
PB-3	Packed Bed -- Sand	Functional
SP-1	Straight Pipe – 60' SCH 40, 1/2" Stainless Steel	Functional
SP-2	Straight Pipe – 10' SCH 40, 1" Galvanized Steel	Functional
SP-3	Straight Pipe – 10' SCH 40, 1" Stainless Steel	Functional
SP-4	Straight Pipe – 10' SCH (), 1" OD Stainless Steel	Functional
SP-5	Straight Pipe – 7' SCH 40, 1" Stainless Steel Sudden Expansion/Contraction	Functional
V-1	Globe Valve	Functional
V-2	Gate Valve	Functional
V-3	Needle Valve	Functional
V-4	Ball Valve	Functional

SUMMARY

Liquid Flow Bench Laboratory Manual

Group G

This student manual was created for the purpose of providing detailed information on the liquid flow bench equipment, and to detail the procedures necessary to operate this equipment. Common theory of Newtonian liquid flow is also detailed in this laboratory manual. The major pieces of equipment are identified and specifications on each are provided. The procedure for operating the dye injection system to obtain different flow profiles was determined and is given. Other common procedures that will improve the basic operation of the liquid flow bench are given.

This manual offers a great deal of information on the equipment as well as excellent information to help future students determine common problems that they may face when operating this equipment. It is recommended that future students obtain this manual from the manuals filed with Bob Cox in MEB 3520 or from their supervising professor. It is also recommended that students should follow the common procedures when facing low flow rates or clogged valves, so that they can overcome these problems quickly and continue with their projects.

INTRODUCTION

The liquid flow bench offers a variety of tools to study basic liquid flow theory. Internal flow through straight pipes, packed beds, valves, and a glass pipe allow for both visual and theoretical study of flow characteristics and friction factors over a wide range of flow rates. The liquid flow bench located is located in senior laboratory. Many experiments can be completed using the liquid flow bench: such as pressure drop and friction factors across different pipes, valves, bends, flowmeters, etc; friction factor reduction do to modification of the water to a solution; flow through packed beds of three varieties, and visual demonstrations of flow profiles.

A detailed description of many parts of the liquid flow bench is provided in the equipment section of this manual. Most piping is made of schedule 40 stainless steel. The tank is filled by turning on the pump power and initiating the fill tank switch. The water is passed through the system by the system pump, which is also initiated by a switch. Before starting the flow bench pump always make sure that the appropriate valves are opened or at least open the recycle valve slightly. Before starting any experiments the system should be thoroughly analyzed, piping should be traced, and the electrical system should also be understood. When measuring pressure drop with the pressure transducers, the pressure taps must be connected and air must be vented on each side.

THEORY

Flow Through a Straight Pipe

A cross-section and side view of a pipe is shown in Figure 1 below with several of the variables used for calculations labeled. All symbols are defined in the nomenclature section at the end of the text.

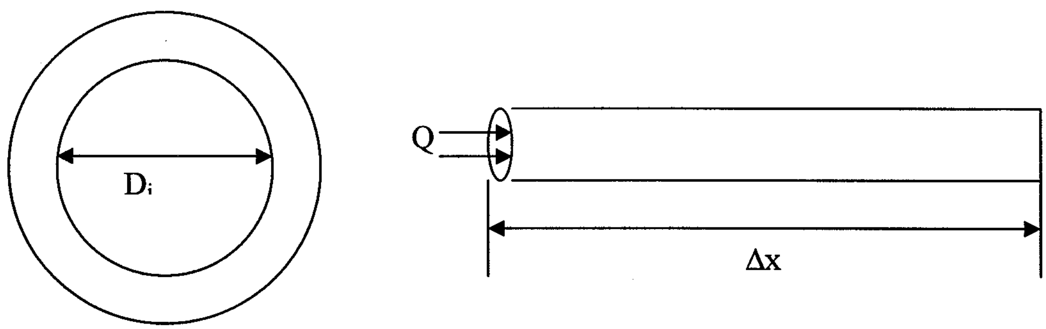


Figure 1. Cross-section and side view of straight pipe in the liquid flow bench system.

All types of flow are characterized by determining the Reynolds number for the flow using

$$R_e = \frac{D_i V \rho}{\mu}. \tag{1}$$

The velocity term in Equation 1 can be substituted using the following relationship

$$V = \frac{Q}{A_c} = \frac{4 \cdot Q}{\pi D_i^{\,2}}, \tag{2}$$

which yields a revised Reynolds number expression of

$$R_e = \frac{4 \cdot Q \rho}{\pi D_i \mu}. \tag{3}$$

The value of the Reynolds number (the ratio of inertia to viscous forces) indicates several characteristics about the flow. In the case of incompressible flow in a straight pipe, Reynolds number values less than 2000 are characterized as laminar flow and exhibit a pressure drop per unit length proportional to the flow rate.

Reynolds numbers larger than 10,000 in a straight pipe, are classified as turbulent flow and exhibit a pressure drop per unit length proportional to the flow rate to a power between 1.8 and 2.0, which is dependent on the roughness of the pipe and other considerations.

Reynolds number values between 2000 and 10,000 in a straight pipe are called transitional, because results are not easily reproducible due to unpredictable switches between laminar and turbulent behavior.

It is also possible to calculate the friction factor for turbulent flow through the pipe shown in Figure 1 by the expression

$$f = \frac{F}{4(\Delta x / D_i)(V^2 / 2)}. \tag{4}$$

The friction loss, *F*, in Equation 4 represents the mechanical energy that is converted to internal energy, or heat. For incompressible flow in a horizontal pipe, where gravitational forces have a negligible effect, Bernoulli's equation can be simplified to yield the following relationship for the friction loss,

$$F = \frac{-\Delta P}{\rho}. \tag{5}$$

Substitution of Equation 5 for the friction loss and Equation 2 for the flow velocity into the expression for the friction factor yields

$$f = \frac{\pi^2 \Delta P D_i^5}{32 \cdot \Delta x \rho Q^2}. \tag{6}$$

The equations for the Reynolds number and the friction factor both rely on a temperature dependant physical property for the flow being evaluated. For the friction factor, the density of the flow must be known and for the Reynolds number, the viscosity of the flow must be known. These temperature dependent properties are readily available for water at any temperature, but may need to be experimentally determined for other process materials.

Flow Through a Packed Bed

The set-up of a packed bed is similar to that of a straight pipe; the primary difference being that the packed bed is oriented vertically and filled with a packing media. As such, the variables for the packed bed are the same as those noted for the straight-pipe in Figure 1.

The process flow through a packed bed can be characterized by determining the Reynolds number value for the flow using:

$$R_e = \frac{D_P V_S \rho}{\mu(1-\varepsilon)}. \tag{7}$$

The superficial velocity term, V_S, in Equation 7 can be calculated as the volumetric flow rate divided by the column's cross sectional area,

$$V = \frac{V_S}{\varepsilon} = \frac{Q}{A_c \varepsilon}, \tag{8}$$

which yields a revised Reynolds number expression of

$$R_e = \frac{D_P Q \rho}{\mu(1-\varepsilon) A_c}. \tag{9}$$

For a packed column, laminar flow is characterized by a Reynolds number less than 10 and turbulent flow by a Reynolds number greater than 1000. The transition region occurs for Reynolds numbers between 10 and 1000.

Although it is not possible to visually see the difference between laminar and turbulent flow through the packed beds of the liquid flow bench, it is possible to measure the pressure drop across the packed beds for a wide range of flow rates. Knowing the pressure drop makes it possible to evaluate the friction loss, F as described in Equation 5. The suitable form for the friction factor for flow through a porous media is given by:

$$f = \frac{D_p \varepsilon^3 F}{\Delta x (1-\varepsilon) V_S{}^2}. \quad (10)$$

Substitution of Equation 5 for the into the expression for the friction factor in Equation 10 yields,

$$f = \frac{\Delta P D_p \varepsilon^3}{\Delta x \rho (1-\varepsilon) V_S{}^2}. \quad (11)$$

More detailed information about flow through packed beds or other instruments, piping, and valves can be obtained from fluid dynamics textbooks.

EQUIPMENT LIST AND SPECIFICATIONS

1. Tank (Pictured in Figure E-1)
   The tank is made up of welded steel, with a diameter of 3 feet, and a height of roughly 4 feet (before level sensor). The pump has a level sensor that will sometimes shut off the pump that fills the tank. Never let the tank overfill and the level sensor is no guarantee to stop the tank from being overfilled.
   The tank is filled from a service water inlet pipe at the top, and gravity drains to sewer system at the bottom as well as passed to the liquid flow bench pump through a side outlet near the bottom of the tank.

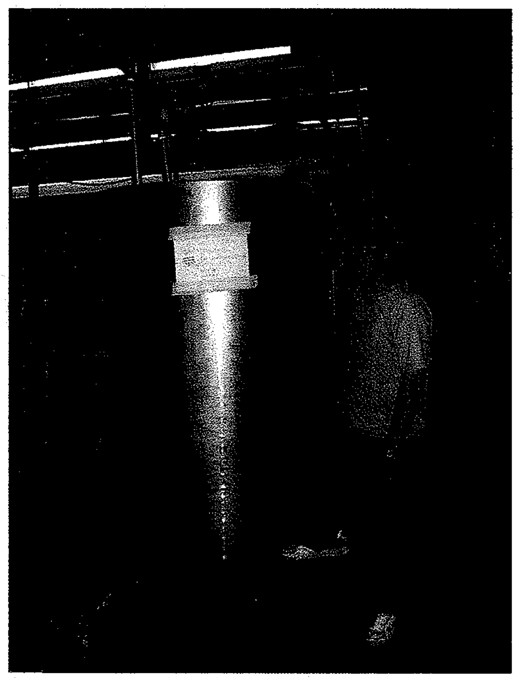


Figure E-1. Photograph of liquid flow bench holding tank with Michael Gregory to indicate relative size.

2. Liquid Flow Bench Pump Pump (Pictured in E-2)
   Cast Iron High-Head Pump
   Sta-Rite JHF-51HL, 60 cycle series centrifugal pump with 1 ½ horsepower motor.
   RPM = 3450, Pump specifications given on the following page.
   Incoming pipe diameter = 2 inch, Schedule 40 stainless steel
   Outlet pipe diameter = 1 ½ inch, Schedule 40 stainless steel

Liquid Flow Bench Pump Specifications

www.mcmaster.com

Cast Iron High-Head Centrifugal Pumps

Built to power liquids up and out. They pump to higher heads than standard centrifugal pumps with the same horsepower. Discharge can be rotated in 90° increments. Pumps are close-coupled and have Buna-N/ceramic mechanical seals. Motor is open dripproof, capacitor start with built-in thermal overload protection and automatic reset; has shielded ball bearings and a Type 416 stainless steel shaft; is permanently lubricated; and generates 3450 rpm. Maximum temperature is 140° F for pumps with abrasion-resistant polycarbonate impeller; 225° F for pumps with brass impeller. Materials in contact with solution are polycarbonate, cast iron, and brass.

	Pump Performance gpm @ head, ft.			Shutoff,	VAC		Full Load	Connections, NPT Female		Polycarbonate Impeller		Brass Impeller	
hp	20	60	80	ft.	@ 60 Hz	ph.	Amps	Intake	Discharge	Each		Each	
1/3	30	15	5	85	115	1	9.4	1 1/4"	1"	4291K31	$174.26	4291K61	$262.64
1/2	40	21	5	85	115/230	1	9.4/4.7	1 1/4"	1"	4291K32	191.21	4291K62	282.45
3/4	47	30	20	100	115/230	1	12.2/6.1	1 1/4"	1"	4291K33	212.36	4291K63	303.81
1	60	45	37	115	115/230	1	14.8/7.4	1 1/4"	1"	4291K34	237.93	4291K64	318.98
1 1/2	70	55	46	116	115/230	1	19.2/9.6	1 1/4"	1"	4291K55	288.71	4291K65	392.83
2	84	67	55	130	230	1	12	1 1/2"	1 1/4"	4291K56	326.26	4291K66	439.28
2 1/2	92	75	65	145	230	1	12	2"	1 1/2"	4291K57	387.33	4291K67	497.91

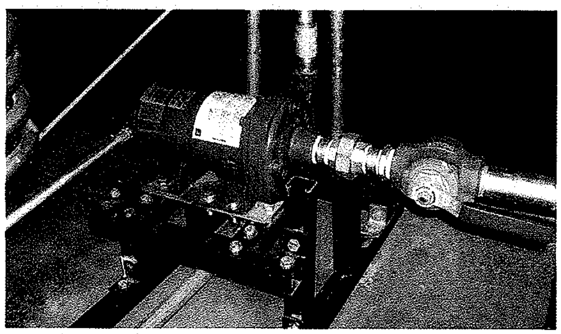


Figure E-2. Photograph of Sta-Rite centrifugal pump.

3. Valves
   -Gate valve by Fairbanks (Pictured in Figure E-3)
   -There are 4 different types of valves that are used in a variety of places along the liquid flow bench. These valves consist of Globe, Gate, Needle, and Ball. Information on each type of valve can be obtained easily from an internet search on each type.

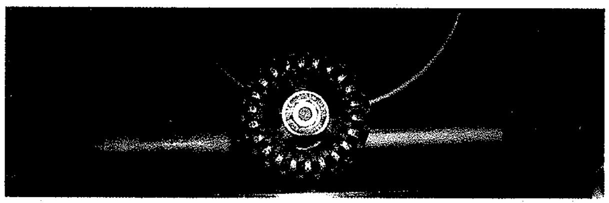
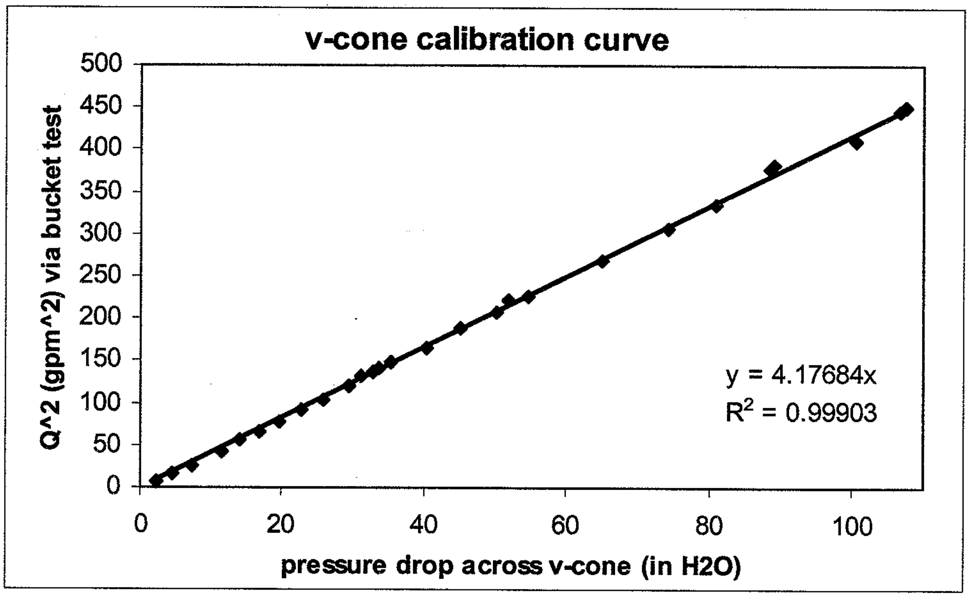


Figure E-3. Photograph of gate valve that controls flow through the liquid flow bench.

4. V-cone Flowmeter (Pictured in Figure E-4)
   Ketema McCrometer v-cone flow analyzer
   Model #V-1401
   Specifications can be obtained in section 6 of this manual.

Figure E-4. Photograph of v-cone flowmeter.



5. Totalizer (Pictured in Figure E-5)
Brooks Instrument Division, inline totalizer, tick marks equal to 0.1 gallon. Detailed specifications and operations manual is provided in section 4 of this manual. The totalizer does not operate well at flow rates much lower than 8 gallons per minute do to the needle sticking. The flow rate is also reduced significantly when passing it through the totalizer.

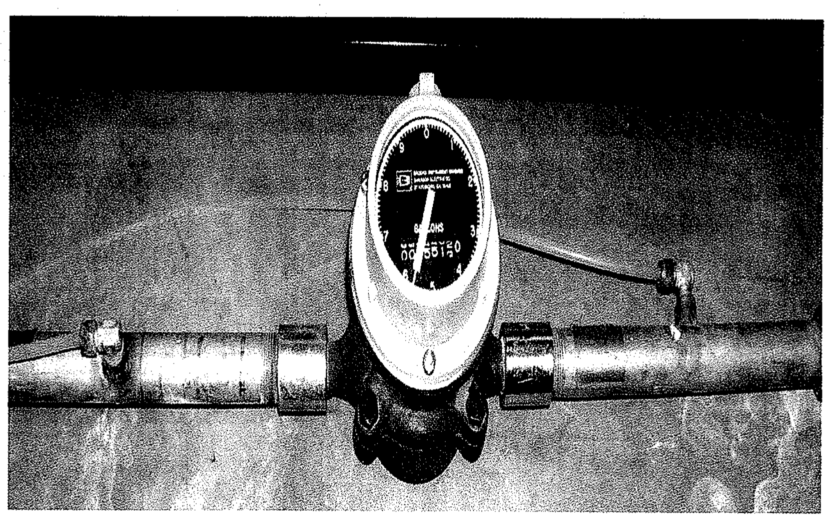
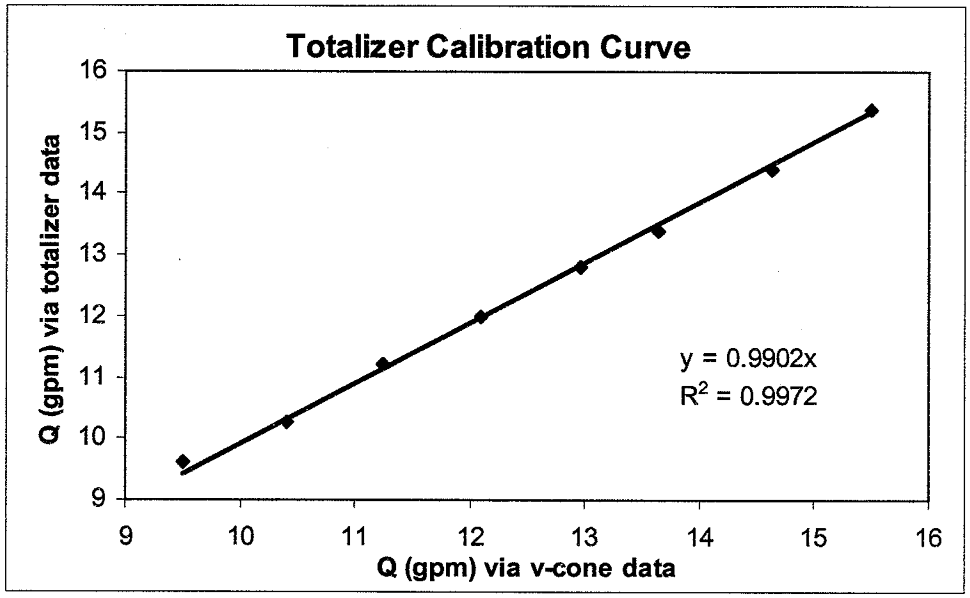
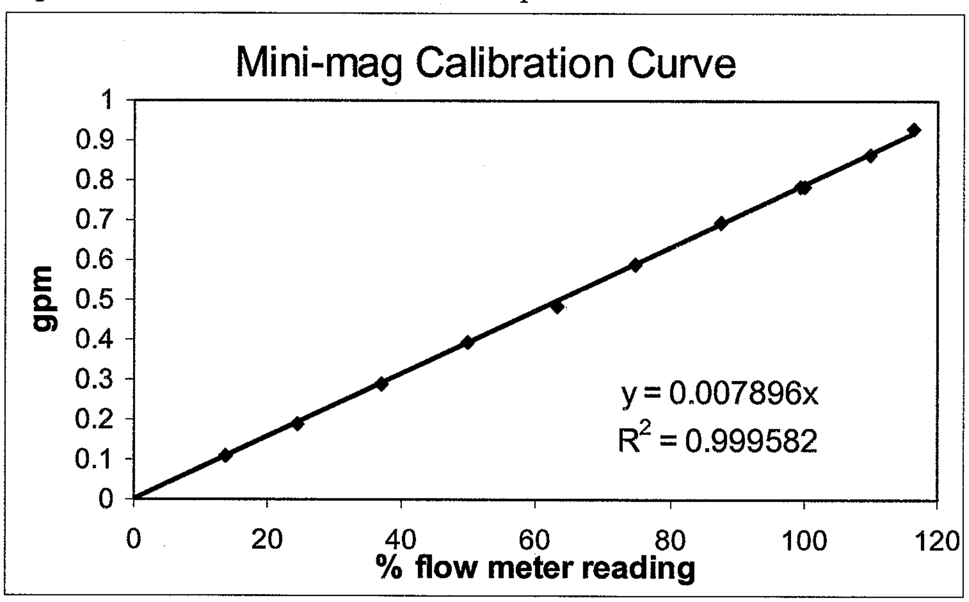


Figure E-5. Photograph of inline totalizer.

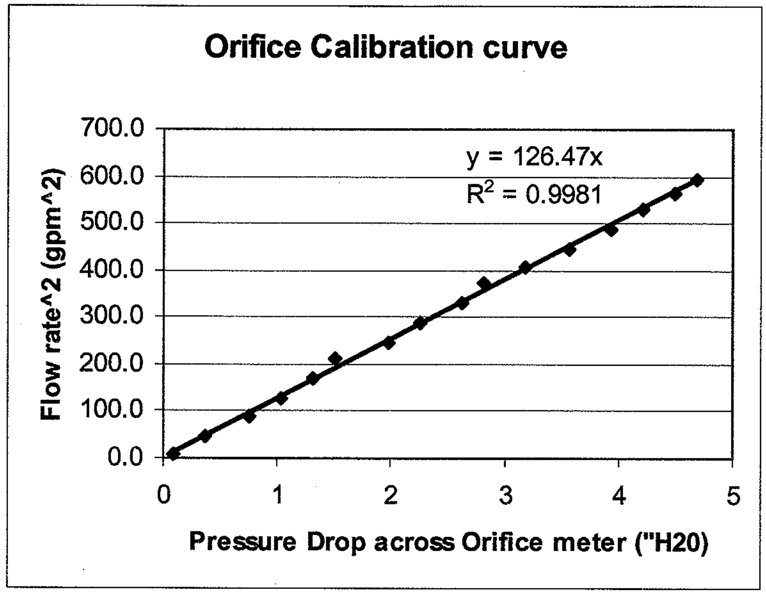


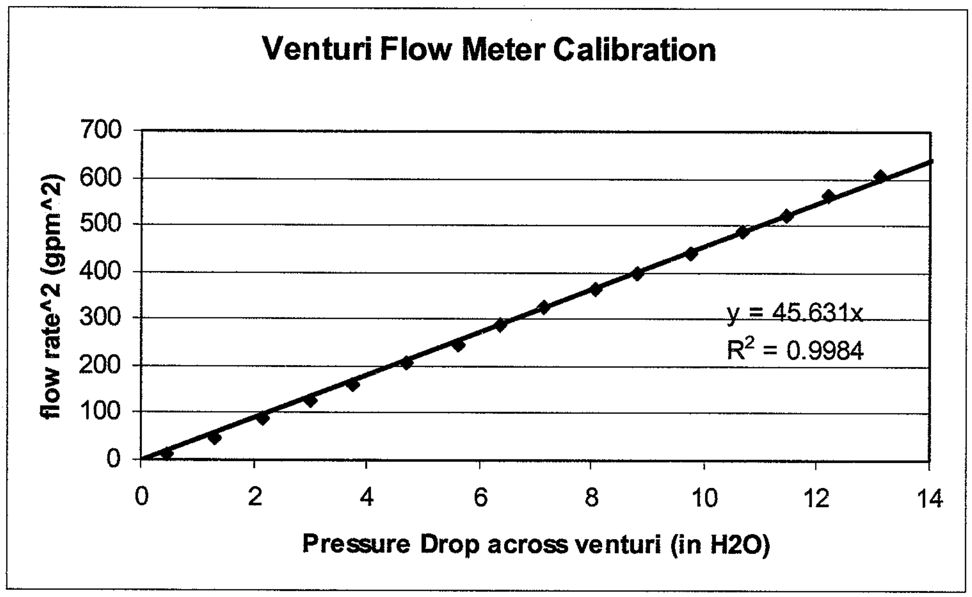
6. Mini-MagX Magnetic Flowmeter (Figure E-8)
   Model 10D1475. This flowmeter only operates at very low flow rates, from 0 to 0.9 gallons per minute. An instruction manual is provided in section 5 of this manual.



7. Brooks Full-View Rotameter (Figure E-8)
   Model 1110. This flowmeter also operates at low flow rates, from 0 to 1.1 gpm. An operation manual is provided in section 7. The calibration was checked and the rotameter operated within standard error.

8. Venturi and Orifice Meters
   These meters are very common and information on each can be obtained from any web site on liquid flow measurement. Calibration curves were fit to the data obtained and are given below. The inside diameter of the orifice is 0.865 cm.





9. Series of Pipes (Pictured in Figure E-6)
   Made primarily with Schedule 40 stainless steel pipes of various diameters:
   All pipe lengths are between pressure taps. The pipes are:
   60' long ½" diameter Schedule 40 stainless steel pipe
   10' long 1" diameter Galvanized steel pipe
   10' long 1" diameter Schedule 40 stainless steel pipe
   10' long 1" diameter O.D. Schedule 20 stainless steel pipe
   7' long ¾" diameter Schedule 40 stainless steel pipe, 3' long 1/2" diameter pipe contraction.
   2 45° elbows, 2 90° elbows, 1 180° smooth turn around, and a 5 ½ ring coil and appropriate piping (not seen in figure)

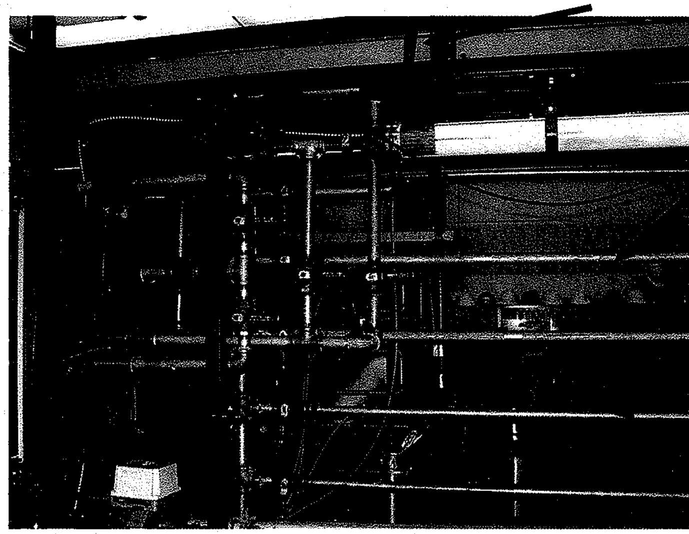


Figure E-6. Photograph of liquid flow bench with pipes used for experimentation labeled.

10. Pressure drop measurement system (Pictured in Figure E-7)
    Rosemount Model 1151 Pressure Transmitters
    - -output range of 4-20 mA.
    - -Max W.P. 2000 psi
    - -Supply 45 Voc. Max

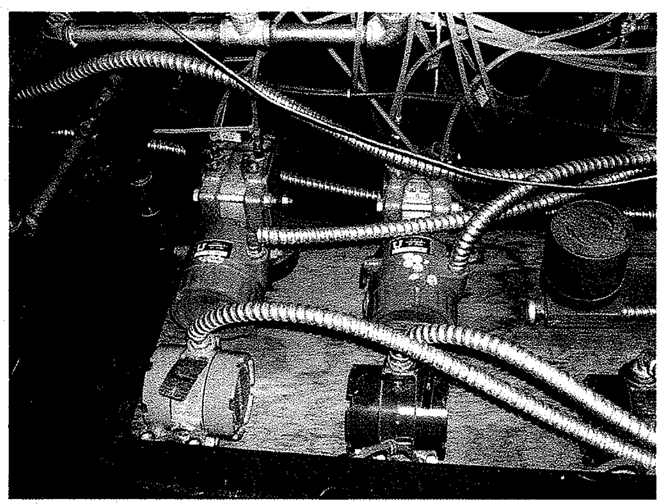


Figure E-7. Photograph of pressure transducer manufactured by Rosemount.

11. Digital Display (Pictured in Figure E-8)
    D.C. Milliamps digital display manufactured by Simpson.
    Displays for the pressure drop ranges of 0-0.24, 0-1.2, 0-5.0, 0-30, 0-150, and 0-750 Inches of water.

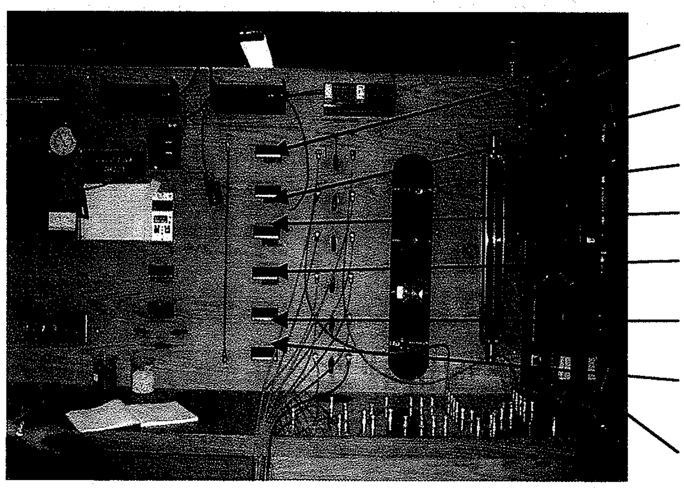


Figure E-8. Pressure drop digital display in mA.

12. Packed Beds (Pictured in Figure E-9)
    Three 8" diameter glass columns in parallel
    Various packing materials:

    ½" diameter glass beads
    1 cm catalyst pellets
    1 mm diameter sand grains

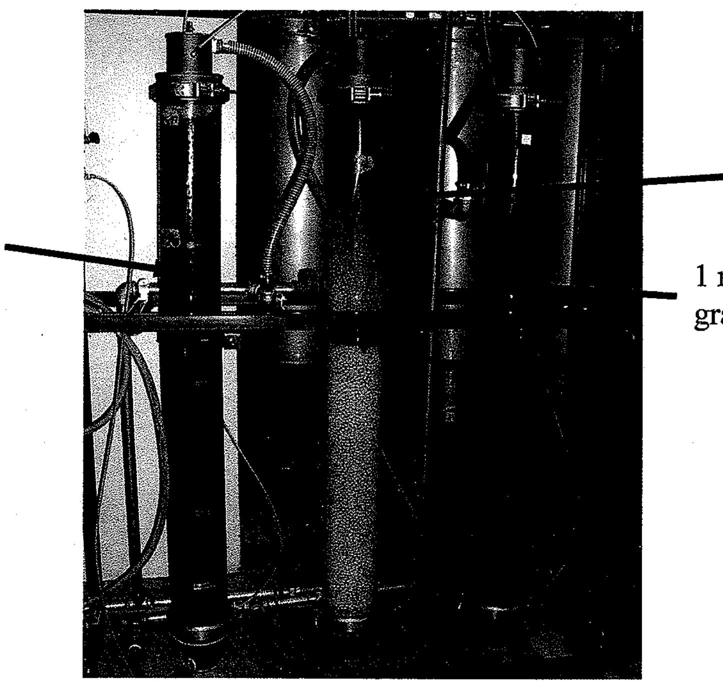


Figure E-9. Photograph of packed beds containing (from left to right) glass beads, catalyst pellets and sand grains.

13. Site-glass pipe used for dye injection visual demonstration (Pictured in Figure E-10)
    10' long, 6" diameter clear pipe with ink injector

Figure E-10. Photograph of site-glass pipe used for visible inspection of flow type.

14. Dye Injection pump (Pictured in Figure E-11)
    Micro-pump 115 Vac. 9 Amp. pump
    p/n: 000-415-000

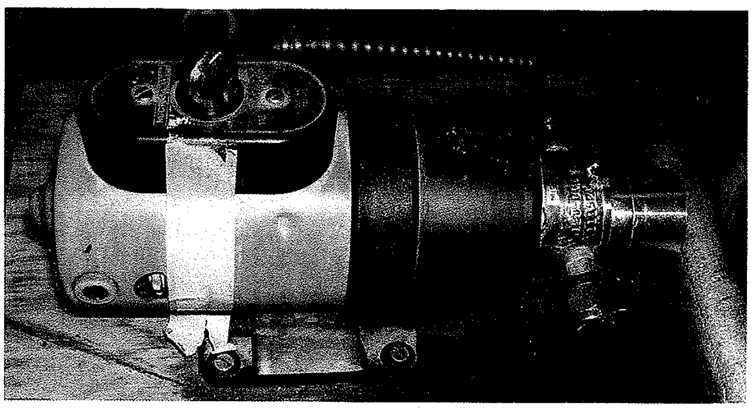


Figure E-11. Photograph of dye injection pump.

15. Other objects that no longer function on the liquid flow bench are the turbine flowmeter, and the disk flowmeter (replaced by the totalizer). Manuals for these pieces of equipment are given in section 7 of this manual. It is possible to bring the turbine flowmeter back on line.
16. The piping and flow of water through the system can be traced out at the liquid flow bench or viewed on the attached flow sheet to this manual.