PUMP CHARACTERISTICS AND FLOW MEASUREMENT EXPERIMENT

A. SAFETY

1. Wear safety glasses at all times,

2. Wear jeans or slacks, a long sleeved shirt, and sturdy shoes that give good traction on possibly wet floors.

3. Guard against electrical hazards by making sure that all equipment is well grounded using three-wire plugs and other means. All components should be plugged into the GFCI protected power strip provided with the experiment.

4. Guard against falls, burns, Cuts, and other physical hazards.

5. THINK FIRST OF SAFETY IN ANY ACTION YOU TAKE. If not certain, ask the TA or a faculty member before you act

6. Loose clothing and long hair should not be worn near rotating equipment such as the belt-driven pumps.

7. The safety shield over the gears and gear belt should be in place at all times. When moving the gear belt it is ESSENTIAL that the motor control power switch, the power strip switch, and the GFCI switch be OFF, to prevent accidental running of the motor.

B. OVERVIEW

The goals in carrying out this experiment are:

- To calibrate the orifice meter, turbine meter, rotameter and ultrasonic flowmeter over a range of flow rates.
- To determine, for the gear pump and for the centrifugal pump, the discharge pressure as a function *of* flow rate and rotational speed.
- To determine also for both pumps the efficiency as a function of rotational speed and flow rate.

C. SCENARIO

LACIMEHC CHEMICAL Inc. makes significant capital investments each year in pumps, and spends additional money in electrical power for driving these pumps. (A large pump driven by a 100 kW motor will use almost $90,000 per year of energy, assuming a cost of 10 cents per kWhr.) LACIMEHC also invests in many kinds of flow meter, without a clear understanding of which kind is best suited for a given service. The management, in its wisdom, has decided to form a small group to make independent tests on various pumps and flow meters, in order to acquire data that can be used to minimize pumping costs and improve flow meter purchases. Your assignment, should you choose to accept it, is to develop a small test bed for investigating pump and flow meter performance.

D. APPARATUS

In the attached schematic diagram, the major components are as follows:

Tanks

Both tanks are polycarbonate, of internal height about 11.75 inches, volume about 20 L, and with top ID = 11 11/16 inches (29.69 cm) and bottom ID = 10 7/8 inches (27.62 cm). The upper tank is equipped with a ball valve in the line that extends through the varnished plywood support and is used to drain water into the lower tank. The bottom tank connects to the PVC pump inlet piping via a brass union. The volume V (cm^3) of the tank as a function of vertical water level h (cm) is given by:

$$V(h) = (pi/4)(a_l^2 h + a_l a_2 h^2 + a_2^2 h^3/3)$$

where a_l = 27.62, a2 = (29.69 - 27.62)/30.48 = 0.0679.

The volume between the lower and upper marks is 9.78 L.

Pumps and Variable Speed Motor

Two pumps are mounted on an aluminum base plate. The bronze centrifugal pump is equipped with a 20-tooth timing belt pulley. The stainless gear pump (Teel) is equipped with a 30-tooth pulley. The gear pump outlet line *(1/2"* stainless tubing) is equipped with a pressure relief valve set for about 25 psig, in order to prevent overstressing the polymeric gears. Each pump has a stainless ball valve in the outlet line. Each pump can be connected to a *114* hp variable speed DC motor (Bodine) driven by a Bodine Type FPM speed controller, and with a 20-tooth gear belt pulley. The maximum motor speed is 2500 RPM, set by a dial and indicated by an Omega panel meter. An Omega pressure transducer (range 0 to 30 psig) measures the pump discharge pressure. The DC motor is mounted on ball bearings, and is equipped with an arm that presses on an Omega LCGC-IKG load cell. The load cell drives an Omega DP25-E display. The effective length of the arm relative to the centerline of the motor shaft is 4.125 inches.

Flow Measurement Instruments

A Dwyer differential pressure transducer (range 0 to 20 psid) measures the pressure drop across the orifice, and drives an Omega DP25-E display. The orifice plate (1/16 inch stainless) is mounted in a stainless orifice flange and sealed with O-rings. The orifice diameter supplied is 0.250 inches. The orifice plate is easily replaced, and a larger diameter, for example, would allow a greater maximum flow rate.

The flow passes next through a turbine meter (A W Company, Serial Number 05190372, 0.75 - 7.5 GPM) that is connected to a JV -400 amplifier and an LLC-O 1 meter. The LLC-O 1 drives a display that shows either frequency (Hz) or total pulses. The nominal meter calibration is 11,414 pulses per gallon, but this will be checked during the course of the experiment. (The display can be programmed to indicate in units such as gallons per minutes, liters/second, etc.)

The flow passes next through a polysulfone rotameter with a nominal flow rate range of 0.5 to 7 gallons of water per minute.

An Omega ultrasonic flow meter is mounted on the *1/2* inch stainless tubing (tubing ID = 0.43 inches, tubing area = 0.937 cm^2) connecting the rotameter outlet to the upper tank. The ultrasonic meter transducer is clamped lightly to the stainless tubing, with a silicone coupling agent used between the transducer and the tubing. The flow meter is battery powered, with a nominal battery life *of* 30 hours. The meter automatically turns *off* about 2 minutes after being turned on.

E. THEORY

Torque and Power

The torque exerted by the motor is the product of the lever arm length and the force on the load cell. The load cell is calibrated by resting a known weight (typically about 300 g) on the small ball bearing that presses on the load cell center pin, after zeroing (tare button) the display. For example 298 grams will typically produce a reading of 227 meter units. The lever arm length in this experiment is the horizontal distance between the motor shaft centerline and the button on the load cell.

The power delivered to the belt and then to the pump is given by the formula P = 2 Pi NT, where N is the rotational speed in revolutions per second, T is the torque in Newtons, and P is power in Watts. This can be compared to the power delivered to the water, namely the product of the volumetric flow rate *(m^3/s)* and the pressure drop across the pump (Pa = *N/m^2).* The efficiency of the pump is then the ratio of the power absorbed by the fluid to the power supplied by the motor. With small pumps such as those supplied, efficiency may be quite low due to factors such as friction in the bearings, turbulence in the pumps, and backflow in the gear pump. Gear and centrifugal pumps are very different in construction and operation. As a first approximation, a gear pump is a positive displacement device, in the sense that it delivers a flow rate proportional to pump speed and independent of discharge pressure. In contrast, a centrifugal pump delivers a discharge pressure proportional to pump speed, and independent of flow rate. In the present experiment, closing the ball valve in the centrifugal pump discharge line causes no problems, while closing the ball valve in the gear pump discharge line could destroy the polymeric gears.

Sample Calculation

As hypothetical data, assume:
Lever arm length 4 inches = 0.1016 m
Calibrating weight = 300 g = 0.300 kg
Load cell reading = 300 meter units (μ)

Then

Force = 9.81 m/s^2 0.300 kg = 2.943 N

Load cell factor = 2.943 N/.100 meter **unit** = 0.00981 N/μ

Now assume:

N = 2000 RPM = 2000/60 = 33.33 rev/s

Load cell reading = 350 meter units

Load cell force = 0.00981 × 350 = 3.433 N

Torque = T = 0..1016 m 3.433 N = 0.3488 N m

Power = P = 2 Pi 1333 8"-1 0.3488 N m = 73.05 W

If the volumetric flow rate is

3 GPM = 3 gal min^{-1} 0.13368 ft^3 gal^{-1} 0.02832 m^3 ft^{-1} (1/60) min s^{-1} = 0.000189 m^3/s

and the discharge pressure is

20 lb_f/in^2 = 20 lb_f /in^2 6894.7 N/m^2 = 137,894 N/m^2

then the power is

0.000189 m^3/s 137,894 N/m^2 = 26.06 W

The efficiency of the pump is 26.06/73.05 = 35.68%

Orifice Calculation

The basic orifice equation is

$$u_O = c_O[2\ g_c\ \Delta P / \rho]^{1/2}$$

where u_O (m/s) is velocity, c_O is a coefficient equal to 0.61, g_c= 1 is a conversion factor, ΔP (Pa) is the pressure drop, and ρ (kg/m^3) is the density.

The volumetric flow rate Q (m^3/s) is given by

$Q = A\ u_O$

where A is the orifice area *(*m^2*)*.

Assume that:

orifice diameter = 0.250 inch = 0.00636 m

g_c = 1 (for SI units)

c_O = 0.61 (for turbulent flow)

ρ = 1000 kg/m^3 (for water)

differential pressure meter reading = 2000 meter units (μ)

Then

$$A = (Pi/4)(0.00636)^2 = 0.0000318\ m^2$$

Next

$$\Delta P = (2000\ \mu)(9.856\ Pa/\mu) = 19712\ Pa$$

and

$$u_O = 0.61[2\ 119712/1000]^{1/2} = 3.83\ m/s$$

and

$$Q = .0000318\ 3.83 = 0.000122\ m^3/s$$

and this is equal to 1.953 gpm.

Typical Transducer Calibration Factors

For the pressure sensor, K = 3672 Pa/meter unit.

For the differential pressure transducer, K = 9.856 Pa/meter unit.

For the load cell, K = 0.0212 N/meter unit.

For the turbine meter, K = 11414 pulses/gallon (based on AW Company calibration).

F. PROCEDURE

Flow Meter Calibration

At zero RPM use the panel meter tare buttons to zero the pressure, differential pressure, and torque meters. Open the manual flow control valve fully. Select a pump, connect the pump to the motor using the belt, and adjust the belt tension, avoiding excess tension. If the gear pump is used, make sure the discharge ball valve is open and the centrifugal pump ball valve is closed, and conversely for the centrifugal pump. Operating the gear pump with the discharge valve closed MAY DAMAGE THE PUMP, although the pressure relief valve is designed to prevent this.

Set the motor speed control to FORWARD and the speed knob to zero. Turn on the motor speed power switch. Set the motor speed to, say, 2000 RPM. The lower tank should be almost full, with the water level above the top of the upper yellow tape. The intertank ball valve should be open so that the water recirculates. Turn the ultrasonic meter on and set the mode to m/s. Record all meter readings and the rotameter reading (sharp edge of the float top).

Close the intertank valve. When the water level drops to the top of the upper strip, start a stopwatch. Record the meter readings when the level is midway between the strips. When the level reaches the top of the lower strip, stop the stopwatch. Record the meter readings and the time. The marks are 6 inches apart, corresponding to a volume of Open the intertank valve and allow the upper tank to drain into the lower tank.

Calculate the volumetric flow rate using the average tank area (top inside diameter = 11 11/16 inches, bottom ID = 10 7/8 inches), the distance between the black strips (6.0 inches) and the elapsed time.

Repeat the above procedure for, say, motor speeds of 300, 500, 700, ..., 2300 and 2500 RPM. Plot the orifice reading (psid), turbine meter reading (Hz), rotameter reading (GPM), and ultrasonic meter reading (m/s) as functions of volumetric flow rate (GPM).

Notes: As the level in the lower tank drops, the suction pressure for the pump will vary, but only by about 6 inches of water. Use the average of the upper, middle, and lower readings in the calculations.

Pump Characteristics

Select a pump, set the pump speed to zero, shut *off* pump power and all power to the experiment at the power strip and GFCI, make sure the safety shield is in place, use the belt to connect the selected pump to the motor, tension the belt properly, open the pump discharge valve, close the discharge valve for the unused pump, and open the flow control valve fully.

Open the valve between the upper and lower tanks. Use the tare buttons to zero the load cell and pressure displays. Record the zero flow pressure drop. Set the turbine meter display mode to frequency.

Next, restore power and set the pump speed to a selected value, for example 2000 RPM. Record all meter readings, including the rotameter reading. Close the flow control valve until the pump discharge pressure has increased by, say, 2 psi. Record all meter readings. Continue to close the flow control valve and record meter readings until the discharge pressure is near 25 psig. Repeat the procedure above for a range of pump speeds, say 500, 750, ..., 2250,2500 RPM. You now can calculate (see sample calculations above) the pump efficiency as a function of flow rate and discharge pressure, using the previously obtained calibration curves, for example for the turbine meter.

G. REPORT

The report should describe concisely the goals of the work, what was done, and the results and conclusions. The raw data should appear in an Appendix. Plots of flow rate based on the orifice, rotameter, turbine, and ultrasonic meters versus the rotameter reading should be presented and discussed. Plots of pump efficiency and discharge pressure as functions of RPM and flow rate should be presented and discussed in the body of the report.

H. REFERENCES

1. McCabe, W.L., J .C. Smith and P. Harriot, "Unit Operations of Chemical Engineering, Edition, McGraw-Hill, New York, 1985.

I. COMMENTS

1. A larger orifice would permit higher flow rates, but produce lower pressure drops across the orifice. The present orifice has a diameter 0.250 inches. An increase to 0.280 inches increases the area by a factor of $(0.280/250)^2$ = 1.254 and decreases the pressure drop by a factor of 1.2541^2 = 1.573.

2. At some point it might be desirable to increase the maximum speed of both pumps. This can be done, for example by replacing the 20-tooth gear on the 1/2" motor shaft by a 24-tooth gear bored to 1/2" ID. The belt does not have to be changed. The gears provided allow a maximum gear pump speed of 1667 RPM, less than the rated speed of 1725 RPM. But the gears in the gear pump are polymeric, and must not be overstressed.

3. The most accurate measurements can be obtained by taring the pressure and differential pressure meters with the motor off, turning on the motor, recording the meter reading, taring the meter, turning off the motor, and recording the meter reading again. Then the final reading is half the sum of the absolute values of the two readings.

J. TYPICAL DATA

motor rpm	turbine hz	pump pressure meter rdg	load cell meter rdg	orifice meter rdg	rotameter gpm	ultrasonic m/s
702	191	52.20	53.80	15.00	0.95	1.35
898	247	68.40	58.80	22.00	1.25	1.54
1114	305	89.20	65.70	33.00	1.56	1.81
1310	359	112.20	72.40	45.00	1.87	1.95
1511	415	139.20	79.80	57.00	2.18	2.11
1704	468	167.30	87.50	73.00	2.43	2.25
1900	522	200.50	97.60	89.00	2.70	2.29
2106	579	238.10	109.20	106.00	2.97	2.46
2307	634	278.00	121.30	124.00	3.29	2.57
2451	674	308.50	129.50	135.00	3.48	2.70

Excel can be used to plot the turbine meter, rotameter, orifice meter, and ultrasonic meter readings as functions of pump speed.

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