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A Computer-Based Pump Testing Experiment*

M. BEHNIA
G. L. MORRISON
School of Mechanical and Manufacturing Engineering, University of New South Wales, Kensington, Sydney 2033, *Australia*

K. TAYLOR
BHP Iron Ore Pty Ltd, Port Hedland, Australia.

A manually operated pump test rig has been modified to allow interfacing with a personal computer and full automation of the test sequence. The computer performs the tests from start to finish without any intervention by the operator. The pump performance characteristics can be presented either in tabular or graphical form. The computerized test rig allows tests to be performed at several pump speeds in a very short period of time

SUMMARY OF EDUCATIONAL ASPECTS OF THE PAPER

1. The paper describes new training tools or laboratory concepts/instrumentation/experiments in:
   Mechanical engineering and chemical engineering.
2. The paper describes new equipment useful in the following courses or graduate work:
   Fluid mechanics/engineering experimentation.
3. Level of students to be involved in the use of the equipment;
   Second- and third-year undergraduates.
4. What aspects of your contribution are new?
   Integration of computer with a pump testing experiment. Control of parameters, data recording and presentation.
5. How is the material presented to be incorporated in engineering teaching?
   The material can be used in an experiment for teaching fluid mechanics or experimental techniques in engineering.
6. Which texts or other documentation accompany the presented materials?
   Laboratory instructions for performing the experiment and a computer help menu accompanies the presented material.
7. Have the concepts presented been tested in the classroom or in project work? What conclusions have been drawn from the experience?
   The experiment has been performed by a large number of second- and third-year undergraduate students. A better understanding of pump performance testing has been obtained as it is possible to collect data over a wide operating range in a short period of time.
8. Other comments on the benefits of your presented work for engineering education:
   The integration of a computer with such experiments is essential for teaching modern mechanical engineering.

INTRODUCTION

IN OUR second-year undergraduate fluid mechanics subject, one of the experiments that students perform is a pump performance test. The objectives of this experiment are to obtain and plot the characteristics of a small centrifugal pump at selected speeds. The laboratory period is scheduled for two hours and the students are expected to collect the data, perform the calculations and plot the results during this period. Over the years that this experiment has been performed, it has been realized that in order to complete the objectives within the given time, it is not possible to obtain enough data points at different pump speeds to show clearly the pump performance characteristics. Therefore, it was deemed essential that the data collection be automated by proper instrumentation and interfacing with a personal computer (PC).

To this end, the existing pump test rig in our hydraulics laboratory was modified. The objectives were to select and install proper instrumentation that could be easily interfaced with a PC. A computer program was developed which collected the data from the transducers via an analogue to digital (AD) card and performed the pump performance calculations as well as plotting the

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results. The program controlled the rig and changed the required parameters for obtaining the complete pump performance curve. In the modification of the rig particular attention was paid to the cost of the instruments to ensure that the overall cost was reasonable for an undergraduate experiment. However, care was taken to ascertain that the pump test accuracy was as far as possible within the range specified in the relevant Australian and International Standards.

This paper describes, firstly, the unmodified pump test rig, and secondly, the modifications to each part of it for interfacing with the computer. Sample results of tests performed by the computer are presented. The results indicated that it was possible to obtain an accurate pump performance curve in a reasonably short time.

PUMP TEST RIG

A schematic diagram of the unmodified pump test rig is shown in Fig. 1. The rig consists of a reservoir containing ~300 l of water with the pump and motor mounted adjacent to the reservoir. The pump outlet is connected to a 44 mm (i.d.) vertical pipe of 1500 mm length with a bend and then a horizontal pipe section about 2500 mm long. For flow measurement, an orifice plate is placed in the horizontal pipe with a valve downstream of it for flow regulation. The orifice plate pressure drop is measured by a mercury manometer. Water is returned to the reservoir via a calibration tank, which in conjunction with a stop watch is also used for measuring the flow rate. The pump is a small centrifugal type (113 mm impeller diameter) with a maximum flow rate of 3.3 l/s. It is driven by an electric motor (0.75 kW) which is mounted on trunnion bearings. A spring balance is fitted to the electric motor for torque measurement. The motor is driven by an electronic frequency type speed controller and its speed is measured by a hand-held optical tachometer. The pump inlet and outlet pressures are measured by mechanical spring type dial gauges.

Prior to starting the pump, the spring balance is adjusted to read zero and then the speed controller is turned on and set at the desired value. At this fixed pump speed, the flow rate is varied by the regulating valve from fully closed to fully opened. At each flow rate, the pump inlet and outlet pressures as well as the pressure drop across the orifice plate is measured. The spring balance force is read and the calibration tank is filled with the duration of filling period measured by the stop watch.

The power required to drive the pump (shaft power: $\dot{W}_s$) is calculated by multiplying the spring balance reading by the torque radius of the trunnion balance and the rotational speed of the motor. As the pump inlet and outlet diameters are equal, the mechanical energy equation is simplified to give the total head increase across the pump:

$$H = \Delta P/\rho.g \qquad (1)$$

where ΔP is the measured pressure difference across the pump, ρ is the water density and g is the gravitational acceleration. The power delivered by the pump to the water is:

$$\dot{W}_w = Q.\Delta P \qquad (2)$$

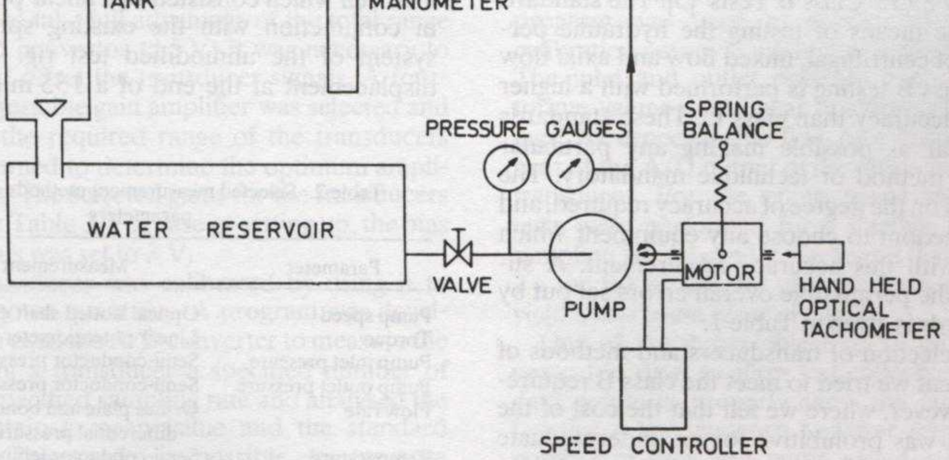

Fig. 1. A schematic of the unmodified, manually operated pump test rig.

Table 1. ISO Standards permissible errors in measurements

	Permissible Errors (± %)	
Measured Quantity	**Class B**	**Class C**
Flow Rate	2.0	3.5
Pump Total Head	0.5	2.0
Pump Power Input	1.5	3.5
Speed of Rotation	0.5	1.4

where Q is the measured volumetric flow rate. Therefore, the overall efficiency (%) of the pump is determined from:

$$\eta = \frac{\dot{W}_w}{\dot{W}_s} \times 100 \qquad (3)$$

Once these values are determined at each flow rate for a given pump speed, then the pump head and efficiency are plotted as a function of the pump flow rate.

COMPUTERIZED RIG

The conversion of the above manual pump test rig required replacement of the measuring instruments by transducers which can be easily interfaced with a PC and providing means for the computer to control pump speed and the flow control valve. Further, appropriate software was developed to perform a test automatically and calculate and plot the pump performance curve. In the process of selecting the transducers and methods of measurements, particular attention was paid to minimizing the cost. It was necessary to measure parameters accurate enough to meet the requirements of the relevant Australian Standard.

The Australian Standard pertinent to pump testing is AS 2417 [1], which is based on the International Standards, ISO 2548 'Class C tests' [2] and ISO 3555 'Class B Tests' [3]. The standard sets out the means of testing the hydraulic performance of centrifugal, mixed flow and axial flow pumps. Class B testing is performed with a higher degree of accuracy than class C. These standards avoid as far as possible making any particular measuring method or technique mandatory. The emphasis is on the degree of accuracy required, and there is freedom to choose any equipment which complies with this accuracy requirement. A summary of the permissible overall errors set out by the standards is given in Table 1.

In our selection of transducers and methods of measurement we tried to meet the class B requirements; however, where we felt that the cost of the instrument was prohibitive for an undergraduate experiment, class C levels were used as error limits.

The PC used for this experiment had a 128 K RAM board and was fitted with a clock card and an A/D converter. The clock card was capable of performing timing operations with an accuracy of 1 ms. The A/D converter had a 12-bit resolution and was interfaced with a 16-channel multiplexer. The converter required a signal in the range of −5 to +5 V. The computer was also equipped with a 16-bit pulse counter as well as a two-channel 12-bit D/A card. A printer was connected to the computer so that the students could obtain a hardcopy of the results for their analysis and report. In selection of measuring methods of the required parameters, ease of interfacing with the above computer as well as accuracy and cost were considered. After examining a number of different methods and transducer types, the optimum measuring methods were chosen as listed in Table 2.

Pump speed was measured by counting pulses generated by an optical switch and a perforated plate attached to the motor shaft. The plate has 60 perforations and the pulses are counted using the 16-bit counter. At the maximum speed of about 2800 r.p.m. this would lead to the counter overflowing after about 20 s. Hence all the pump speed measurements must be taken over a period of less than 20 s. The interval between counter readings is timed with a resolution of 1 ms which together with the 60 pulses generated per revolution allows extremely accurate speed measurements with estimated errors of less than 0.1%.

The motor torque was measured by designing a load cell which consisted of a linear potentiometer in conjunction with the existing spring balance system of the unmodified test rig. The vertical displacement at the end of a 155 mm horizontal

Table 2. Selected measurement methods of different parameters

Parameter	Measurement method
Pump speed	Optical slotted shaft encoder
Torque	Linear potentiometer load cell
Pump inlet pressure	Semi-conductor pressure transducer
Pump outlet pressure	Semi-conductor pressure transducer
Flow rate	Orifice plate and bonded strain gauge differential pressure transducer
Temperature	Semi-conductor temperature transducer

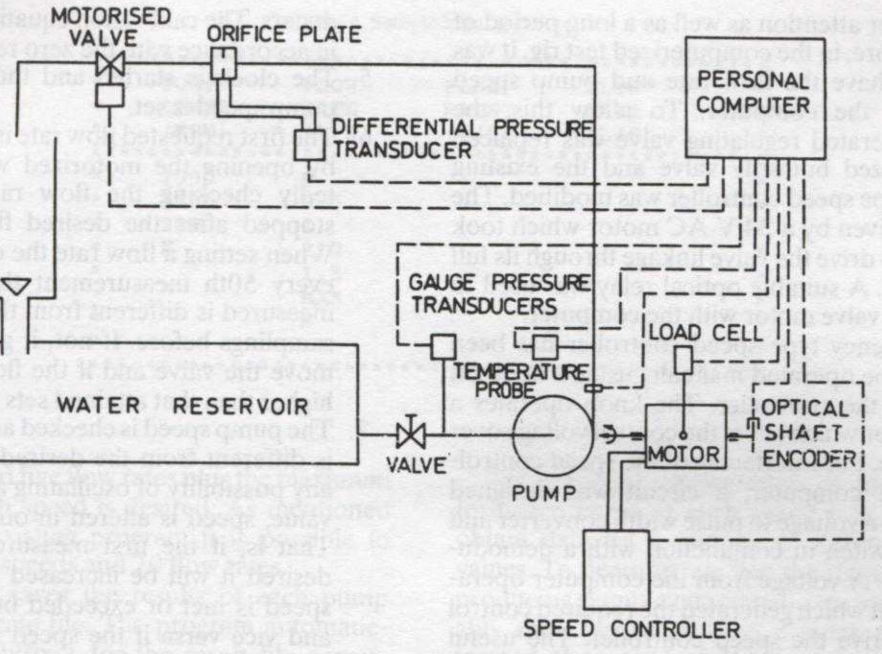

Fig. 2. A schematic of the computerized pump test rig.

arm was measured by the potentiometer, which had a full-scale displacement of 30 mm. This displacement was related to the spring force, from which the torque could be calculated.

The inlet and outlet pressure tappings were modified and fitted with T type outlets so that the dial type pressure gauges and semi-conductor transducers could be connected simultaneously. Both semi-conductor pressure transducers had a range of 2 bars (gauge). For the pump flow rate measurement, a 25 mm diameter orifice plate in conjunction with a 1 bar bonded strain gauge differential pressure transducer was used. The water temperature was measured by inserting a semi-conductor temperature probe at the outlet of the pump. This probe is a highly stable device containing internal logic which delivers a current outlet signal whose value in miocroamps is equal to the absolute temperature. A schematic of the modified pump test rig is shown in Fig. 2.

In order to take full advantage of the total range of the A/D convertor (±5 V) it was necessary to amplify and offset the transducer signals. A four-channel adjustable gain amplifier was selected and tests over the required range of the transducers were performed to determine the optimum amplifier settings. The selected gains for the transducers are given in Table 3. For ease of setting up, the bias for all signals was set to 3 V.

Each transducer was calibrated by using it to measure known quantities. A program was developed which used the A/D converter to measure the output from a transducer a specified number of times at a specified sampling rate and analysed the data to obtain a mean value and the standard deviation. This made it possible to measure unsteady quantities with a sufficient number of samples for the mean to be insignificantly different from the true mean. It also allowed a resolution smaller than the least significant bit of the A/D converter.

Table 3. Optimum amplifier settings

Transducer	**Amplifier Gain**
Inlet pressure	200
Outlet pressure	50
Flow rate	500
Torque	1

Once the calibration data for the pressure transducers, linear displacement potentiometer and temperature probe was collected, a regression program was used to obtain the appropriate calibration curves as a function of the A/D output. The inlet and outlet pressure, temperature and torque values were linear functions of A/D readings. As expected, the flow rate varied as square root of the A/D output of the differential pressure transducer. For the pump speed measurement, tests were performed for a number of different sampling periods and it was found that a period of 2 s for the measuring of pulses was adequate to yield a maximum error of 0.05%.

One of the major objectives of modifying the pump test rig is to allow fast collection of enough data points to properly show the pump characteristics. A test sequence, however, requires a large number of flow and pump speed combinations, which if controlled manually would require constant operator attention as well as a long period of time. Therefore, in the computerized test rig, it was essential to have the flow rate and pump speed adjusted by the computer. To allow this, the manually operated regulating valve was replaced by a motorized butterfly valve and the existing frequency type speed controller was modified. The valve was driven by a 24 V AC motor which took about 84 s to drive the valve linkage through its full range of 95°. A suitable optical relay was used to interface the valve motor with the computer.

The frequency type speed controller has been designed to be operated manually using a knob on the front of the controller. The knob operates a potentiometer which alters the control voltage over a 10 V range. For interfacing of the speed controller with the computer, a circuit was designed consisting of a voltage to pulse width converter and an optical switch in conjunction with a demodulator. The D/A voltage from the computer operated the circuit which generated the required control voltage to drive the speed controller. The useful range of the digital to analogue voltage provided an adequate resolution to vary the pump speed by 3 r.p.m. for 1 bit.

SOFTWARE

A computer program was written for the operation of the computerized test rig, collection of the data and plotting the results. In order to minimize the required testing time, most of the program related to the data collection was written in machine language with the rest in BASIC. In order to provide ample digital filtering and ensure that the mean value of a reading was negligibly different from the true mean during the sampling period, for each point approximately 3000 readings were averaged. The main features of the program are briefly as follows:

1. The user is given the option of either performing a test or plot the previously saved data.
2. The user is asked to specify a file name for storing the measured data.
3. The user is asked to specify the desired pump speeds and flow rates. There is also an option to read the desired values from a file. If the user chooses to specify the data, the desired pump speeds are specified in a column of a table on the screen. Up to 14 pump speeds can be specified and the reading of the pump speeds is terminated by writing N in this column. The desired flow rates are specified in three separate columns, allowing up to 70 values to be specified, N prompts the termination of the input flow rates and MAX indicates the motorized valve should be fully opened to allow maximum flow rate. Once the desired pump speeds and flow rates are given, they are stored.
4. The computer performs an equipment self-check and reads the zero reading of all transducers. The calibration equations are adjusted in accordance with the zero readings.
5. The clock is started and the first requested pump speed is set.
6. The first requested flow rate is set. This is done by opening the motorized valve and repeatedly checking the flow rate; the valve is stopped after the desired flow is achieved. When setting a flow rate the computer checks every 50th measurement that the flow just measured is different from that measuring 50 samplings before. If not, it gives up trying to move the valve and if the flow specified was higher than that attained sets a flag.
7. The pump speed is checked and fine-tuned if it is different from the desired value. To avoid any possibility of oscillating about the desired value, speed is altered in only one direction. That is, if the first measured is below that desired it will be increased until the desired speed is met or exceeded but not decreased and vice versa if the speed first measured is above that desired.
8. Measure and record inlet and outlet pressures, flow rate, pump speed and torque.
9. Perform the pump efficiency and head calculations.
10. Repeat steps 6–9 for all flow rates.
11. Measure and record the temperature.
12. The clock is stopped and the data are saved in the results file.
13. Steps 5–12 are repeated for all pump speeds.
14. The pump test is finished and the pump is stopped and the user is requested to specify the form of data presentation. Either tabular or graphical presentation is possible.
15. If tabulated results is requested, the performance data is displayed on the screen with an option for printing.
16. If graphical presentation is requested, the plotting routines are called and appropriate scaling is determined (to fill the whole screen) for displaying a composite graph of pump head and efficiency versus flow rate. A printing option is also given.

Further details of the program and its listings as well as the details of the hardware can be obtained from the authors.

RESULTS

After the modifications of the manual test rig were performed, the transducers were calibrated and the computer program was written and debugged. Then the test rig interfaced with the computer was fully commissioned. In order to check the proper and satisfactory operation of the rig and the computer a number of tests were performed.

A sample of an input test file containing the required pump speeds and flow rates is given in Table 4. In this test three pump speeds are selected

Table 4. Sample input test data

```
**************************************************
*    PUMP      FLOW       FLOW      FLOW         *
*    SPEED     RATE       RATE      RATE         *
*    (RPM)     (L/S)      (L/S)     (L/S)        *
**************************************************
*    1000      0                                 *
*    1500      0.5                               *
*    2000      1                                 *
*    N         1.2                               *
*              1.5                               *
*              MAX                               *
*              N                                 *
*                                                *
**************************************************
```

and at each speed five flow rates plus the maximum flow rate at each speed is desired. As mentioned earlier, in the existing program it is possible to specify up to 14 speeds and 70 flow rates.

The program saves the results of each pump speed in a separate file. The program automatically chooses a suffix 1 for the result file corresponding to the first speed and so on (e.g. RESULTS1.LIST). The computer successfully performed the test at the three speeds and saved the results in three files. The contents of the three results files are given in Table 5. At the speeds of 1000 and 1500 r.p.m., the pump is not capable of delivering flow rates of 0.5 l/s or above and therefore the computer performs the test at zero and maximum flow rates.

For a proper presentation of the pump performance curve at each speed it is necessary to obtain data for a number of different flow rate values. To demonstrate that the rig was capable of producing pump characteristic curves in a reasonably short period of time, a pump test was performed at a speed of 2650 r.p.m. at 32 different flow rates. The tabulated results are presented in Table 6. The pump head and efficiency curves as a function of flow rate are shown in Fig. 3. Once the desired pump speed and flow rates were specified and the test was initiated, it took only 12 min to perform the test and plot the data. The computer generated pump performance curves were confirmed by comparing them with the manually obtained data.

Table 5. Tabulated sample results of a pump test at different speeds

```
                      RESULTS OF PUMP TEST RUN
                        TEMPERATURE = 18.7 C

FLOW (L/S)            0    .098
HEAD (M)              1.89 1.86
EFFICIENCY (%)        0    6.13
INLET HEAD (M)        0    0
OUT. HEAD (M)         1.89 1.86
TORQUE (NM)           .284 .279
SPEED (RPM)           998  997

                      RESULTS OF PUMP TEST RUN
                        TEMPERATURE = 18.8 C

FLOW (L/S)            0    .224 .251
HEAD (M)              3.29 3.27 3.16
EFFICIENCY (%)        0    6.87 7.68
INLET HEAD (M)        -.06 -.06 -.06
OUT. HEAD (M)         3.13 3.11 3.1
TORQUE (NM)           .648 .646 .645
SPEED (RPM)           1499 1500 1499

                      RESULTS OF PUMP TEST RUN
                        TEMPERATURE = 18.8 C

FLOW (L/S)            0    .532 1.04 1.22 1.53 2.15
HEAD (M)              8.18 7.76 7.12 6.86 6.32 4.92
EFFICIENCY (%)        0    26.7 40.7 43.4 46.3 44.4
INLET HEAD (M)        .024 .01  -.02 -.04 -.07 -.14
OUT. HEAD (M)         8.21 7.77 7.1  6.82 6.25 4.77
TORQUE (NM)           .649 .726 .85  .905 .978 1.12
SPEED (RPM)           2004 1997 1999 2000 1999 2000
```

Table 6. Tabular pump test results at 2650 r.p.m.

```
                       RESULTS OF PUMP TEST RUN
                         TEMPERATURE = 17.2 C

FLOW (L/S)          0    .4   .485 .574 .636 .726 .8   .886
HEAD (M)            14.8 14   13.9 13.9 13.9 13.8 13.7 13.6
EFFICIENCY (%)      0    16.1 19.1 22.3 24.4 27.1 29.2 31.5
INLET HEAD (M)      -.05 -.03 -.03 -.04 -.04 -.05 -.07 -.08
OUT. HEAD (M)       14.5 14   13.9 13.9 13.8 13.7 13.6 13.5
TORQUE (NM)         1.15 1.23 1.25 1.27 1.28 1.31 1.33 1.35
SPEED (RPM)         2654 2649 2648 2651 2648 2648 2650 2648

FLOW (L/S)          .952 1.03 1.13 1.23 1.3  1.43 1.51 1.58
HEAD (M)            13.5 13.3 13.2 13   12.9 12.7 12.6 12.4
EFFICIENCY (%)      33   34.8 36.7 38.1 39.4 41.2 42.1 43.4
INLET HEAD (M)      -.1  -.12 -.14 -.18 -.2  -.25 -.28 -.32
OUT. HEAD (M)       13.4 13.2 13.1 12.8 12.7 12.5 12.3 12.1
TORQUE (NM)         1.37 1.4  1.44 1.48 1.51 1.56 1.6  1.61
SPEED (RPM)         2651 2650 2651 2650 2648 2649 2649 2648

FLOW (L/S)          1.69 1.81 1.87 1.97 2.08 2.17 2.28 2.35
HEAD (M)            12.3 12   11.9 11.7 11.5 11.3 11   10.8
EFFICIENCY (%)      44.4 45.9 46.5 47.2 47.8 48.2 48.6 48.7
INLET HEAD (M)      -.36 -.42 -.45 -.5  -.56 -.6  -.67 -.71
OUT. HEAD (M)       11.9 11.6 11.5 11.2 10.9 10.7 10.4 10.1
TORQUE (NM)         1.65 1.68 1.7  1.73 1.76 1.8  1.83 1.85
SPEED (RPM)         2650 2649 2648 2648 2647 2649 2649 2649

FLOW (L/S)          2.45 2.55 2.64 2.74 2.82 2.92 3.01 3.1
HEAD (M)            10.6 10.3 10   9.79 9.53 9.19 8.83 8.51
EFFICIENCY (%)      48.7 48.7 48.5 48.4 48   47.3 46.4 45.7
INLET HEAD (M)      -.78 -.84 -.91 -.98 -1   -1.1 -1.2 -1.3
OUT. HEAD (M)       9.79 9.46 9.14 8.81 8.49 8.06 7.63 7.24
TORQUE (NM)         1.88 1.91 1.93 1.96 1.98 2    2.03 2.04
SPEED (RPM)         2647 2648 2647 2648 2650 2650 2649 2650
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Fig. 3. Graphical pump test results at 2650 r.p.m.

CONCLUSIONS

A manually operated pump test rig has been successfully modified to allow interfacing with a personal computer. Suitable and reasonably priced transducers have been used for measuring the required parameters. A computer program has been written for collection of data, calculation of pump performance characteristics and plotting the results. Once the desired pump speeds and flow rates are specified, the computer performs the tests at different speeds from start to finish without any need for operator intervention. The computerized test rig can be used to determine the pump characteristics for several rotational speeds in a very short period of time. The rig can be used for teaching pump performance characteristics as well as instrumentation, data logging and control.

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Masud Behnia is presently an associate professor in the school of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, Australia. He has earned his B.S., M.S., and Ph.D. all in Mechanical Engineering from Purdue University, USA. His teaching and research interests are fluid mechanics, heat transfer, thermodynamics and multiphase flow. He has published over 80 papers.