Designation: F 2105 – 04

Standard Test Method for Measuring Air Performance Characteristics of Vacuum Cleaner Motor/Fan Systems[1]

This standard is issued under the fixed designation F 2105; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining air performance characteristics of series universal motor/fan systems used in commercial and household upright, canister, stick, hand-held utility, combination-type vacuum cleaners, and household central vacuum cleaning systems.

1.2 These tests and calculations include determination of suction, airflow, air power, maximum air power, and input power under specified operating conditions.

NOTE 1—For more information on air performance characteristics, see References **(1)** through **(6)**.[2]

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

E 1 Specification for ASTM Liquid-in-Glass Thermometers
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
F 395 Terminology Relating to Vacuum Cleaners
F 431 Specification for Air Performance Measurement Plenum Chamber for Vacuum Cleaners

2.2 *AMCA Standard:*
210-85 Laboratory Methods of Testing Fans for Rating[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *air power, AP, W*, *n*—in a vacuum cleaner motor/fan system, the net time rate of work performed by an air stream while expending energy to produce an airflow by a vacuum cleaner motor/fan system under specified air resistance conditions.

3.1.2 *corrected airflow, Q, cfm*, *n*—in a vacuum cleaner motor/fan system, the volume of air movement per unit of time under standard atmospheric conditions.

3.1.3 *input power, W*, *n*—rate at which electrical energy is absorbed by a vacuum cleaner motor/fan system.

3.1.4 *model*, *n*—designation of a group of vacuum cleaner motor/fan systems having the same mechanical and electrical construction.

3.1.5 *population*, *n*—total of all units of a particular model vacuum cleaner motor/fan system being tested.

3.1.6 *repeatability limit (r)*, *n*—value below which the absolute difference between two individual test results obtained under repeatability condition may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.7 *repeatability standard deviation* (S_r), *n*—standard deviation of test results obtained under repeatability conditions.

3.1.8 *reproducibility limit (R)*, *n*—value below which the absolute difference between two test results obtained under reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.9 *reproducibility standard deviation* (S_R), *n*—standard deviation of test results obtained under reproducibility conditions.

3.1.10 *sample*, *n*—group of vacuum cleaner motor/fan systems taken from a large collection of vacuum cleaner motor/fan systems of one particular model which serves to provide information that may be used as a basis for making a decision concerning the larger collection.

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[1] This test method is under the jurisdiction of ASTM Committee F11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.22 on Air Performance.

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[2] The boldface numbers in parentheses refer to the list of references appended to this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from Air Movement and Control Association, Inc. 30 West University Dr., Arlington Heights, IL 60004-1893.

3.1.11 *standard air density,* ρ_{std}, lb/ft^3, *n*—atmospheric air density of 0.075 lb/ft^3 (1.2014 kg/m^3).

3.1.11.1 *Discussion*—This value of air density corresponds to atmospheric air at a temperature of 68°F (20°C), 14.696 psi (101.325 kPa), and approximately 30 % relative humidity.

3.1.12 *suction, inches of water*, *n*—in a vacuum cleaner motor/fan system, the absolute difference between ambient and sub-atmospheric pressure.

3.1.13 *test run*, *n*—definitive procedure that produces the singular result of calculated maximum air power.

3.1.14 *test station pressure,* B_t, inches of mercury, *n*—for a vacuum cleaner motor/fan system, the absolute barometric pressure at the test location (elevation) and test time.

3.1.14.1 *Discussion*—It is not the equivalent mean sea level value of barometric pressure typically reported by the airport and weather bureaus. It is sometimes referred to as the uncorrected barometric pressure (that is, not corrected to the mean sea level equivalent value). Refer to 5.5 for additional information.

3.1.15 *unit*, *n*—single vacuum cleaner motor/fan system of the model being tested.

4. Significance and Use

4.1 The test results allow the comparison of the maximum air power at the vacuum cleaner motor/fan system inlet under the conditions of this test method.

5. Apparatus

5.1 *Plenum Chamber*—See Specification F 431.

5.2 *Water Manometers*, or equivalent instruments. One to measure from 0 to 6 in. (152.4 mm) in increments of 0.01 in. (0.254 mm), and one with increments of 0.1 in (2.54 mm) for use in making measurements above 6 in. (152.4 mm).

5.3 *Wattmeter*, to provide measurements accurate to within ±1 %.

5.4 *Voltmeter*, to provide measurements accurate to within ±1 %.

5.5 *Barometer*, with an accuracy of ±0.05 in. of mercury (1.27 mm of mercury), capable of measuring and displaying absolute barometric pressure, scale divisions 0.02 in. (0.51 mm) or finer.

5.5.1 Mercury barometers, in general, measure and display the absolute barometric pressure. Some corrections may be needed for temperature and gravity. Consult the owner's manual.

5.5.2 When purchasing an aneroid or electronic barometer, be sure to purchase one which displays the absolute barometric pressure, not the mean sea level equivalent barometric pressure value. These types of barometers generally have temperature compensation built into them and do not need to be corrected for gravity.

5.6 *Sharp-Edge Orifice Plates*—See specifications in Specification F 431.

5.7 *Thermometer*—Solid-stem, ambient thermometer having a range from 18 to 89°F (or –8 to +32°C) with graduations in 0.2°F (0.1°C), conforming to the requirements for thermometer 63°F (63°C) as prescribed in Specification E 1.

5.8 *Psychrometer*—Thermometers graduated in 0.2°F (0.1°C).

5.9 *Voltage, Regulator System*, to control the input voltage to the vacuum cleaner motor/fan system. The regulator system shall be capable of maintaining the vacuum cleaner motor/fan system's rated voltage ±1 % and rated frequency ±1 Hz having a wave form that is essentially sinusoidal with 3 % maximum harmonic distortion for the duration of the test.

6. Sampling

6.1 A minimum of three units of the same model vacuum cleaner motor/fan system, selected at random in accordance with good statistical practice, shall constitute the population sample.

6.1.1 To determine the best estimate of maximum air power for the population of the vacuum cleaner motor/fan system model being tested, the arithmetic mean of the maximum air power of the sample from the population shall be established by testing it to a 90 % confidence level within ±5 %.

6.1.2 Annex A2 provides a procedural example for determining the 90 % confidence level and when the sample size shall be increased.

NOTE 2—See Annex for Method of determining 90 % confidence level.

7. Preparation for Test

7.1 Mount the vacuum cleaner motor/fan system unit to the plenum chamber by any convenient method meeting the requirements of 7.1.1-7.1.5.1. See Fig. 1 for an example of a motor mounted to the plenum chamber.

7.1.1 The motor/fan system inlet shall be centered with respect to the outlet opening of the plenum chamber.

7.1.2 The motor/fan system inlet shall be mounted to the plenum chamber such that the inlet does not project into the plenum chamber.

7.1.2.1 If necessary, mount the motor/fan system to a standoff pipe, having an inside diameter of 4 in. and suitable length to prevent the motor/fan system inlet from projecting into the plenum chamber. See Fig. 2 for an example.

7.1.3 Secure the motor/fan system unit to the plenum chamber such that it does not rotate when the motor starts.

7.1.4 Seal all leaks between the motor/fan system inlet and the plenum chamber by any convenient means. See Fig. 3 for example of mounting gasket and plate used to create a seal.

FIG. 1 Motor Mounted to Plenum Chamber

FIG. 2 Example of Standoff Pipe

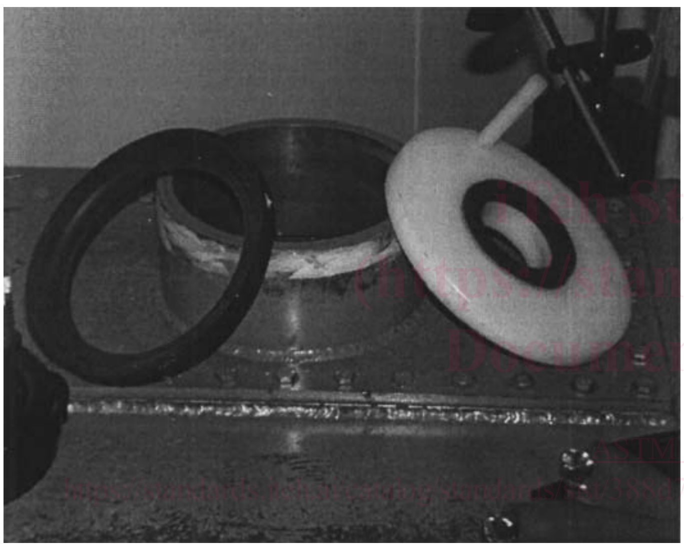

FIG. 3 Mounting Plate and Gasket

7.1.5 For vacuum cleaner motor/fan systems requiring a part from the vacuum cleaner housing to complete the fan chamber, it is acceptable to mount the motor/fan system to this part and in turn mount the fan chamber's inlet to the plenum chamber.

7.1.5.1 It may be necessary to modify the vacuum cleaner housing by any convenient means to allow the fan chamber inlet to be mounted per 7.1-7.1.4. The modifications shall not effect performance.

7.2 Connect the motor/fan system to the power supply using a length of cable of sufficient size to maintain rated voltage at the motor/fan system electrical terminals.

7.3 Set the manometers to zero and check all instruments for proper operation.

7.4 Record the test station pressure and the dry-bulb and wet-bulb temperature readings within 6 ft of the test area. Read the barometric pressure to the nearest 0.02 in. (0.51 mm), and the dry-bulb and wet-bulb temperatures to the nearest 0.2°F (0.1°C).

7.5 Connect a manometer or equivalent instrument to the plenum chamber.

7.6 Connect a wattmeter and a voltmeter in the line in accordance with Fig. 4.

7.7 *Wattmeter Correction*—If needed, the indication may be corrected for voltmeter and wattmeter potential coil loss by opening the load circuit on the load side of the wattmeter with the line voltage at the operating value. The wattmeter current connection may be at its most sensitive position. Subtract this loss value from the total load indication to obtain the true load. As an alternative method, use the following equation:

$$W_C = W_I - V^2 / R_T$$

where:

W_C = corrected wattage,
W_I = indicated wattage,
V = voltmeter reading, and
R_T = $R_\rho \times R_V / (R_\rho + R_V)$.

where:

R_T = total resistances Ω,
R_ρ = wattmeter potential coil resistance Ω, and
R_V = voltmeter coil resistance, Ω.

8. Test Procedure

8.1 Operate the vacuum cleaner motor/fan system with no orifice plate inserted in the plenum chamber inlet at nameplate rated voltage ±1 % and frequency ±1 Hz prior to the start of the test run to allow the unit to reach its normal operating temperature. For vacuum cleaner motor/fan systems with dual nameplate voltage ratings, conduct testing at the highest voltage. Do this before each test run.

8.2 The vacuum cleaner motor/fan system is to be operated at its nameplate rated voltage ±1 % and frequency ±1 Hz throughout the test. For vacuum cleaner motor/fan systems with dual nameplate voltage ratings, conduct the test at the highest voltage.

8.2.1 Allow the vacuum cleaner motor/fan system to operate at the open orifice for 1 to 2 min between test runs.

8.3 While operating the vacuum cleaner motor/fan system per 8.2, insert orifice plates sequentially into the orifice plate holder of the plenum chamber starting with the largest size orifice and following it with the next smaller orifice plate. Use the following orifice plates: 2, 1½ , 1¼ , 1, ⅞ , ¾ , ⅝ , ½ , ⅜ , ¼ and 0 in. (50.8, 38.1, 31.7, 25.4, 22.2, 19.0, 15.8, 12.7, 9.5, 6.3 mm). The following optional orifice plates may also be used: 2½ , 2¼ , 1¾ , 1⅜ , 1⅛ in. (63.5, 57.2, 44.5, 34.9, 28.6 mm).

8.4 For each orifice plate, record the suction, *h*, and input power, *P*, in that order. All readings should be taken within 10

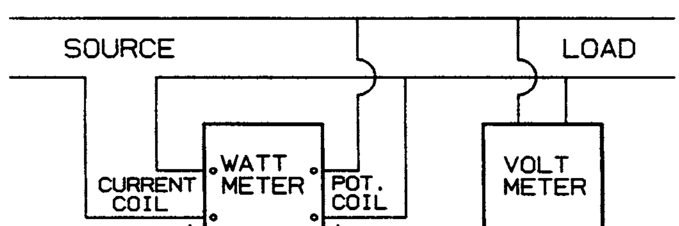

FIG. 4 Schematic Diagram of Meter Connections

s of the orifice insertion. Allow the vacuum cleaner motor/fan system to operate at the open orifice for 1 to 2 min before inserting the next orifice.

8.4.1 Read the suction to the nearest graduation of the manometer. Readings should be taken as soon as the manometer reaches a true peak. (When using a fluid type manometer, the liquid level may peak, drop, and peak again. The second peak is the true peak reading. A person conducting the test for the first time shall observe at least one run before recording data. See Specification F 431 for instructions on how to minimize the overshoot (first peak) of the liquid level.)

9. Calculation

9.1 *Correction of Data to Standard Conditions*:

9.1.1 *Air Density Ratio*—The density ratio, D_r, is the ratio of the air density at the time of test ρ_{test}, to the standard air density, ρ_{std}= 0.075 lb/ft^3(1.2014 kg/m^3). It is used to correct the vacuum and wattage readings to standard conditions. Find ρ_{test}(lb/ft^3 or kg/m^3) from standard psychometric charts or ASHRAE tables and calculate D_r as follows:

$$D_r = \frac{\rho_{test}}{\rho_{std}}$$

where:
ρ_{test} = the air density at the time of test, lb/ft^3, and
ρ_{std} = the standard air density, 0.075 lb/ft^3.

As an alternative, the following equation is intended to be used for correcting ambient conditions where the barometric pressure exceeds 27 in. of mercury and the dry-bulb and wet-bulb temperatures are less than 100°F (37.8 °C); and may be used as an alternate method of calculating D_r (see Appendix X1 for derivation and accuracy analysis).

$$D_r = \frac{[17.68B_t - 0.001978T_w^2 + 0.1064T_w + 0.0024575B_t(T_d - T_w) - 2.741]}{T_d + 459.7}$$

where:
B_t = test station pressure at time of test, inch of mercury,
T_d = dry-bulb temperature at time of test, °F, and
T_w = wet-bulb temperature at time of test, °F.

9.1.2 *Corrected Suction*—Corrected suction, h_s, is the manometer reading, h, times the correction factor, C_s, as follows:

$$h_s = C_s h$$

9.1.2.1 For series universal motor/fan systems (see Ref **(6)**) the correction factor, C_s, is calculated as follows:

$$C_s = 1 + 0.667(1 - D_r)$$

9.1.2.2 This test method does not have any formulas available for correcting suction for any other type of motor (permanent magnet, induction, and so forth).

9.1.3 *Corrected Input Power*—Corrected input power, P_s, expressed in watts, is the wattmeter reading, P, times the correction factor, C_p, as follows:

$$P_s = C_p P$$

9.1.3.1 For series universal motor/fan systems the correction factor, C_p, is calculated as follows:

$$C_p = 1 + 0.5(1 - D_r)$$

9.1.3.2 This standard does not have any formulas available for correcting input power for any other types of motor (permanent magnet, induction, and so forth).

9.2 *Corrected Airflow*—Calculate the corrected airflow, Q, expressed in ft$_3$/min (see Note 3 and Appendix X2) as follows:

$$Q = 21.844D^2K_1\sqrt{h_s}$$

where:
Q = corrected flow, cfm,
D = orifice diameter, in.,
K_1 = constant (dimensionless), orifice flow coefficients for orifices in the plenum chamber. See Table 1 for values for each orifice. See Ref. **(1)** for the derivation of these flow coefficients, and
h_s = corrected suction, in. of water.

NOTE 3—For the corrected airflow expressed in litres per second, use the following equation:

$$Q = 10.309D^2K_1\sqrt{h_s}$$

where:
Q = corrected flow, L/s,
D = orifice diameter, m,
K_1 = constant (dimensionless), and
h_s = corrected suction, Pa.

9.3 *Air Power*—Calculate the air power, AP, in W, as follows:

$$AP = 0.117354\,(Q)(h_s)$$

where:
AP = air power, W,
Q = corrected flow, cfm, and
h_s = corrected suction, inches of water.
(See Appendix X3 for derivation.)

9.4 *Maximum Air Power*—Determine the maximum air power using the method in Annex A1.

10. Report

10.1 For each vacuum cleaner motor/fan system sample from the population being tested, report the following information:

10.1.1 Manufacturer's name and motor/fan system model name or number, or both.

10.1.2 Type of motor/fan system; that is, filter first, fan first, and so forth

10.1.3 The test setup (that is, mounted flush or with standoff pipe) at which the test was conducted.

10.1.4 The corrected input power, corrected vacuum, corrected airflow, and air power for each orifice used.

10.1.5 Calculated maximum air power.

11. Precision and Bias

11.1 The following precision statements are based on interlaboratory tests involving six laboratories and seven units.

11.2 The statistics have been calculated as recommended in Practice E 691.

11.3 The following statements regarding repeatability limit and reproducibility limit are used as directed in Practice E 177.

TABLE 1 Orifice Flow Coefficient Equations (K_1)

NOTE 1—K_1 was determined experimentally using an ASTM Plenum Chamber (see Specification F 431) and an ASME Flowmeter (see Ref. **(1)**).

NOTE 2—Equations for K_1, in terms of B_t and h are given in Appendix X6.

Orifice Diameter, inches (mm)	Orifice Flow Coefficient Equation[A]
0.250 (6.3)	$K_1 = \frac{0.5575r - 0.5955}{r - 1.0468}$
0.375 (9.5)	$K_1 = \frac{0.5553r - 0.5754}{r - 1.0263}$
0.500 (12.7)	$K_1 = \frac{0.5694r - 0.5786}{r - 1.0138}$
0.625 (15.8)	$K_1 = \frac{0.5692r - 0.5767}{r - 1.0104}$
0.750 (19.0)	$K_1 = \frac{0.5715r - 0.5807}{r - 1.0138}$
0.875 (22.2)	$K_1 = \frac{0.5740r - 0.5841}{r - 1.0158}$
1.000 (25.4)	$K_1 = \frac{0.5687r - 0.5785}{r - 1.0146}$
1.125 (28.6)	$K_1 = \frac{0.5675r - 0.5819}{r - 1.0225}$
1.250 (31.7)	$K_1 = \frac{0.5717r - 0.5814}{r - 1.0152}$
1.375 (34.9)	$K_1 = \frac{0.5680r - 0.5826}{r - 1.0235}$
1.500 (38.1)	$K_1 = \frac{0.5719r - 0.5820}{r - 1.0165}$
1.750 (44.5)	$K_1 = \frac{0.5695r - 0.5839}{r - 1.0235}$
2.000 (50.8)	$K_1 = \frac{0.5757r - 0.5853}{r - 1.0157}$
2.250 (57.2)	$K_1 = \frac{0.5709r - 0.5878}{r - 1.0279}$
2.500 (63.5)	$K_1 = \frac{0.5660r - 0.59024}{r - 1.0400}$

[A]

$$r = \frac{B_t(0.4912) - h(0.03607)}{B_t(0.4912)}$$

where:

B_t = test station pressure at time of test, inches of mercury, and

h = uncorrected suction (manometer reading), in. of water.

11.4 The coefficients of variation of repeatability and reproducibility of the measured results have been derived from seven sets of data, where each of the sets have been performed by a single analyst within each of the six laboratories on separate days using the same test samples.[5]

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: F11-1015.

11.5 *Repeatability (Single Operator and Laboratory, Multiday Testing)*—The ability of a single analyst to repeat the test within a single laboratory.

11.5.1 The expected coefficient of variation of the measured results within a laboratory, $CV\ \%_r$, has been found to be 1.25.

11.5.2 The 95 % repeatability limit within a laboratory, r, has been found to be, where r = 3.49 % ($CV\ \%_r$).

11.5.3 With 95 % confidence, it can be stated that within a laboratory, a set of measured results derived from testing a unit should be considered suspect if the percent difference between any two of the three values is greater than the respective value of the repeatability limit, *r* (see Note 4).

NOTE 4—The % difference = [(larger-smaller)/larger] × 100.

11.5.4 If the absolute value of the difference of any pair of measured results from three test runs performed within a single laboratory is not equal to or less than the respective repeatability limit, *r*, that set of results shall be considered suspect.

11.6 *Reproducibility (Multiday Testing and Single Operator Within Multilaboratories)*—The ability to repeat the test within multiple laboratories.

11.6.1 The expected coefficient of variation of reproducibility of the average of a set of measured results between multiple laboratories, $CV\ \%_R$, has been found to be 2.91.

11.6.2 The 95 % reproducibility limit within a laboratory, *R*, has been found to be, where $R = 8.16\%\ (CV\ \%_R)$.

11.6.3 With 95 % confidence, it can be stated that the average of the measured results from a set of three test runs performed in one laboratory, as compared to a second laboratory, should be considered suspect if the percent difference between those two values is greater than the respective values of the reproducibility limit, *R* (see Note 4).

11.7 *Bias*—No justifiable statement can be made on the accuracy of this test method for testing the properties listed. The true values of the properties cannot be established by acceptable referee methods.

12. Keywords

12.1 air performance; air power; motor; motor/fan system; vacuum cleaner

ANNEXES

(Mandatory Information)

A1. MATHEMATICAL METHOD FOR DETERMINING MAXIMUM AIR POWER POINT

A1.1 The following, second degree polynomial equation, is assumed to provide the best mathematical approximation of the air power versus airflow relationship. (See Ref. **(4)** for additional information.)

$$Y = A_1 + A_2X + A_3X^2 \qquad (A1.1)$$

where:

Y = air power (AP),
X = airflow (Q), and
A_1, A_2, A_3 = arbitrary constants

A1.1.1 Use *X* and *Y* values obtained from only five specific orifices selected as follows:

A1.1.1.1 Using the test data, determine the orifice size that produced the highest air power value.

A1.1.1.2 Use the air power and airflow values at this orifice, and the next two smaller and the next two larger orifices in the following computations:

A1.1.1.3 If the highest air power value calculated from the observed data is at the 2.0 in. (50.8 mm) orifice or larger, then use the air power and airflow values from the five largest orifices.

A1.2 To determine the values of A_1, A_2, A_3, use the *X* and *Y* values obtained from the five specified orifices and solve the following set of normalized equations:

$$\Sigma Y_i = NA_1 + A_2\Sigma X_i + A_3\Sigma X_i^2$$

$$\Sigma X_iY_i = A_1\Sigma X_i + A_2\Sigma X_i^2 + A_3\Sigma_i^3$$

$$\Sigma X_i^2Y_i = A_1\Sigma X_i^2 + A_2\Sigma X_i^3\ A_3\Sigma X_i^4$$

where:

N = 5 (number of orifices selected),
I = 1 to N, and
X_i *and* Y_i = the values obtained during testing (X_1Y_1, X_2Y_2, . . X_NY_N) at the five orifices specified in A1.1.1.

A1.3 Setting the derivative of Eq A1.1 equal to zero and solving for *X* will determine the value of X_m where *Y* is at its maximum value (Y_{max}) as follows:

$$\frac{dy}{dx} = \frac{d}{dx}[A_1 + A_2X + A_3X^2] = 0$$

$$\frac{dy}{dx} = A_2 + 2A_3X = 0$$

Substitute X_m as the value of X and Y_{max} and solve for X_m:

$$X_m = -\frac{A_2}{2A_3}$$

Substituting this value of X_m, and A_1, A_2, and A_3, into Eq A1.1 will determine the value of $Y_{max}(AP_{max})$ as follows:

$$Y_{max} = A_1 + A_2X_m + A_3X_m^2$$

A1.4 Calculate the goodness of fit, *R* (correlation coefficient) as follows:

$$R = 1 - \frac{\Sigma\,(Y_{iOBS} - Y_{iCAL})^2}{\Sigma\,(Y_{iOBS} - Y_{OBS})^2}$$

where:

$$Y_{iCAL} = A_1 + A_2X_{iOBS} + A_3X_{iOBS}^2$$

and:

$$Y_{OBS} = \frac{1}{N}\Sigma Y_{iOBS}$$

and:

i = 1 to N orifices used in section 8.3,
OBS = observed data,