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EJECTORS

PERFORMANCE
TEST
CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
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EJECTORS

PERFORMANCE TEST CODES

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FOREWORD

The Performance Test Codes Committee of The American Society of Mechanical Engineers recognized the need for a test code covering steam jet ejectors. Accordingly, in 1948, Performance Test Code Committee No. 24 was organized to prepare such a code. The testing of steam jet ejectors had been covered to some extent previously in the test code covering surface condensers. The special problems involved in ejector testing and the fact that ejectors find their greatest application in industrial process fields rather than in the power plant, required a separate code for this type of equipment.

The original Code was approved by the Performance Test Codes Committee in May, 1956 and adopted by the Council as a standard practice of the Society by the action of the Board on Codes and Standards in June, 1956.

In October, 1969, Performance Test Code Committee No. 24 was reorganized for the purpose of preparing a revised Code which would be more applicable to the art in its present state of development.

This revised Code includes ejectors operated with motive fluids other than steam and was approved by the Performance Test Codes Committee on September 26, 1975 and adopted by the Council as a standard practice of the Society by action of the Policy Board on Codes and Standards on November 17, 1975.

On February 24, 1976, the Board of Standards Review of the American National Standards Institute approved PTC 24 – Ejectors as an American National Standard.

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ASME PERFORMANCE TEST CODES
Code on
EJECTORS

CONTENTS

SECTION 0, INTRODUCTION

0.01 This Code is written for ejectors which are distinguished from other types of compressors as having no moving parts; the work of compression being done by the kinetic energy of the motive fluid issuing from a nozzle at high velocity.

0.02 The basic unit consists of a nozzle, a suction chamber, and a diffuser. A single assembly of these parts is known as a stage, see Fig. 13. Two or more stages may be used in series, varying with the compression ratio, and the combination is referred to as a multi-stage unit. Condenser(s) may be used between stages. The term "ejector system" as used herein refers to the complete ejector assembly which may be either a single stage, or a number of stages, including their respective condenser(s).

0.03 The motive fluid most commonly used in the ejector is steam. Other fluids, such as air and hydrocarbon gases, have application in the process industries.

0.04 Of the suction fluids handled by ejectors, air, steam, and air-vapor mixtures predominate. The pumping of hydro-carbon gases and many other chemicals is not uncommon. The suction pressures, usually below atmosphere, vary widely with the application, and occasionally extend to the low absolute pressure ranges measured in microns.

0.05 There are several test problems peculiarly related to the ejector. The measurement of relatively small flow rates and low absolute pressures requires a special technique. Because of the critical relation between motive-fluid pressure and the stability of the ejector operation, a specific procedure is required to establish acceptable test conditions. This Code provides the necessary instructions.

0.06 Reference is made to the Performance Test Code Supplements on Instruments and Apparatus (abbreviated as I&A) for general instructions on instrumentation. The specific directions of this Code, however, shall prevail for any instrument, procedure, or measurement which may differ from that given in other ASME publications.

0.07 A study of the Code on General Instructions is recommended as an introduction to the essential procedures necessary for proper use of all ASME Performance Test Codes. The mandatory requirements contained therein are incorporated in Section 3 herein.

SECTION 1, OBJECT AND SCOPE

1.01 This Code provides standard directions and rules for the conducting and reporting of tests on single or multi-stage ejector units.

1.02 The primary object of the test measurements described herein is to establish:

(a) Ejector capacity in relation to suction pressure
(b) Discharge pressure in relation to suction pressure
(c) The flow rate of the motive fluid in relation to a stipulated pressure and temperature
(d) The ejector stability; i.e. the relation of motive fluid pressure or the discharge pressure to breakdown and recovery of the pumping action

1.03 The Code rules and procedures are intended primarily for the test of ejectors in which the motive fluid is steam. They may be used, however, with any motive fluid for which the physical properties are completely and reliably known. See Section 3, Par. 3.01.

1.04 The instructions and capacity measurements provide for tests where the suction fluid pumped is air, water vapor, or other gases for which the physical and thermodynamic properties are known. A procedure is provided for tests on gas mixtures in which the components can be separately measured and controlled.

1.05 If the motive fluid is steam or other condensable vapor, it shall be dry (without any moisture). The Code does not cover two-phase fluids.

1.06 This Code is limited to ejectors having suction pressures that permit accurate measurement by the instrumentation and technique available.

1.07 Rules are given for adjusting test results to design conditions. (See Section 3 on Guiding Principles.)

1.08 This Code does not consider an overall tolerance or margin which may, by agreement, be made applicable to any specific performance. Allowances for inaccuracy of measurements may be recognized as provided in Section 3, Par. 3.10.

1.09 The procedures and instrument specifications of Section 4, the formulae and methods for computing results of Section 5, and the indicated form of reporting the test of Section 6, are mandatory. For reasons of expediency or otherwise, the parties to a code test may, by agreement, substitute other instruments or methods. However, only tests made in strict accordance with the mandatory provision of this Code may be designated as complying with the ASME Test Code for Ejectors.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

2.01 Absolute Pressure is the pressure measured from absolute zero; i.e., from an absolute vacuum. It equals the algebraic sum of the atmospheric pressure and the gage pressure.

2.02 Static Pressure is the pressure measured in the gas in such manner that no effect on the measurement is produced by the velocity of the gas.

2.03 Total Pressure is the pressure measured at the stagnation point when a moving gas stream is brought to rest and its kinetic energy is converted by an isentropic compression from the flow condition to the stagnation pressure. It is the pressure usually measured by an impact tube. In a stationary body of gas, the static and total pressures are numerically equal.

2.04 Velocity Pressure is the total pressure minus the static pressure in a gas stream. It is generally measured by the differential reading of a Pitot tube.

2.05 Suction Pressure is the static pressure prevailing at the suction inlet of the ejector expressed in absolute units.

2.06 Discharge Pressure is the static pressure prevailing at the discharge of the ejector expressed in absolute units.

2.07 Motive-Fluid Pressure is the static pressure prevailing at the nozzle inlet expressed in absolute units.

2.08 Total Temperature is that temperature which would be measured at the stagnation point if a gas stream were brought to rest and its kinetic energy converted by an isentropic compression from the flow condition to the stagnation temperature.

2.09 Suction Temperature is the temperature of the fluid at the suction inlet of the ejector.

2.10 Motive-Fluid Temperature is the temperature of the motive fluid at the nozzle inlet.

2.11 Stability is used in this Code to describe a characteristic of the ejector pumping action. If the discharge pressure is too high, or if the motive-fluid pressure is too low, the flow stream at the suction may momentarily reverse and the ejector is said to be unstable. Stable operation is identified as that condition at which the suction pressure is not decreased by either a further decrease in the discharge pressure or a further increase in the motive-fluid pressure. The term does not necessarily apply to single-stage ejectors designed for very low compression ratios nor to multistage ejectors working at suction pressures above their normal range.

2.12 Breaking Pressure is that pressure of either the motive fluid or the discharge which causes the ejector to become unstable.

2.13 Recovery Pressure (Pick-Up Pressure) is that pressure of either the motive fluid or the discharge at which the ejector recovers to a condition of stable operation.

2.14 Specific Weight or Density is the weight of fluid per unit volume under specified conditions of pressure and temperature.

2.15 Specific Gravity is the ratio of the specific weight of gas to that of dry air at standard pressure and temperature. Actual and standard temperatures and pressures *must* be specified.

2.16 Capacity is the weight-rate-of-flow of the fluid compressed and discharged by the ejector. It refers specifically to the stream of gas pumped through the suction inlet of the ejector.

2.17 Motive-Fluid Consumption, for steam or other fluids, is the weight-rate-of-flow passing through the motive nozzle(s) at specified conditions of temperature and pressure.

SECTION 3, GUIDING PRINCIPLES

3.01 Items on Which Agreement Shall Be Reached. A procedure mandatory in the use of this Code, requires the parties to the test to reach agreement on several items related to the test. These are:

(a) The responsibility for obtaining and installing the instruments and controls which are required to conform to this Code.

(b) The responsibility for isolation of the equipment to be tested.

(c) Method of testing multi-component systems. This Code permits testing ejectors in either of the following ways:

(i) as a completely assembled unit with all inter-condensers, usually at plant site.

(ii) by testing the ejector stages separately with agreement reached as to the matching properties, usually done at the manufacturer's testing facilities.

Note: While section (ii) is often used, section (i) shall control if any discrepancies arise.

(d) Intent of specifications as to operating conditions.

(e) Object of test and required measurements.

(f) Range of capacity and stability tests required of the system.

(g) The fluid(s) to be used in capacity measurement.

(h) Method of maintaining constant test conditions such as motive pressure, cooling-water rate, etc.

(i) Method of measuring the flow rates of the suction and motive fluids.

(j) Selection of test arrangement as provided herein to suit the type of ejector(s), the kind of fluids to be measured, and the operating conditions.

(k) The selection of instruments.

(l) Arrangements for calibration of the instruments and fluid meters where required.

(m) Arrangements for examination of the system, for preliminary tests, and the time interval between the initial use in service and the code test. This item is of particular interest if surface condensers are involved.

(n) If a condenser, silencer, or other equipment follows the last ejector stage, agreement shall be reached regarding the location of stations for measuring the discharge pressure of the preceding ejector stage.

3.02 Parties to the test shall designate a person to direct the test and serve as arbiter in regard to the accuracy of observations, or reliability of the operating procedures.

3.03 Representatives of any interested party may, if they so desire, be present at all times during the test to assure themselves that the test is being conducted in accordance with this Code and with any agreement made in advance.

3.04 During preparation for test and before starting any test run, the ejector system shall be placed at the disposal of all interested parties for examination. Dimensions and physical condition, not only of ejector(s) and related equipment, but of all the associated system which may be required in the determination of performance, shall be observed and recorded. After examination and prior to test, the party conducting the test may allow any necessary permanent adjustments to be made to place the ejector system in the proper operating condition.*

3.05 Alternate arrangements of the flow nozzles are provided for the measurement of capacity as described in Section 4. Other methods of flow measurement are given in "Fluid Meters," sixth edition.

3.06 Agreement shall be reached as to the effect of the suction fluid on the entire system if the suction fluid is other than the design composition. Tests using suction fluid other than the design composition, will require evaluation of the effect on the ejector system as a whole. This must include the effect on condenser operating conditions.

3.07 Tests made to establish a single-point capacity shall consist of not less than three load points and they shall bracket the rated value within ± 5 percent of rated capacity. It is recommended that a capacity curve be generated which runs from no load to a load which causes the suction pressure to rise sharply; this is not mandatory.

3.08 The methods of determining stability are given in 4.32, Operating Procedure.

3.09 If cooling water is required, the supply pressure shall be free of fluctuation. Facilities shall be provided for controlling the cooling-water quantity and temperature at the specified values. Cooling-water quality (including gas content, solid content and any foam producing contaminants) shall be suitable for test.

*Exercise care not to void any guarantees.

3.10 The ASME Performance Test Codes *shall not* recognize commercial tolerances which might be applied to the results of tests. The codes shall recognize, however, limits of error of any of the individual measurements or methods of a measurement (Part III, Section I of PTC 1). If any such limits of error are agreed upon, their numerical value and the method of their application to the test result shall be stipulated either in the purchase contract or agreed upon before acceptance tests are commenced and shall be completely described in the test report.

3.11 Preliminary Tests. Preliminary tests may be run for the purpose of:

(a) Determining whether the ejector and associated piping system are in suitable condition for the conducting of a code test.
(b) Checking of instruments.
(c) Training personnel in the operation of the ejector system.
(d) Determining the conditions of stable operation.

3.12 A preliminary test may become the final code test if all of the requirements for a code test were met and it is so agreed by the interested parties.

3.13 Test Conditions. The significant factors to be considered in the planning of a test or for appraising the results are:

(a) Suction pressure
(b) Suction temperature
(c) Discharge pressure
(d) Suction-fluid composition
(e) Suction-fluid rate (capacity)
(f) Pressure limits for operating stability
(g) Quantity of motive fluid
(h) Pressure and temperature of motive fluid
(i) Quality of motive fluid
(j) Cooling-water quantity and temperature

3.14 When testing an ejector, every effort shall be made to have operating conditions as near as possible to design conditions. The maximum deviation for which adjustment may be made to any of the variables is given in Table 1. Under these conditions, the value of variables, as calculated under the rules of this Code, shall be accepted as indicating the performance of the ejector.

3.15 If inconsistencies arise, either during a test or during the computation of results, the test shall be rejected in whole or in part and shall be repeated.

3.16 Instruments. The selection of instruments required to conduct tests under this Code is specified in Section 4. The initial calibration of the instruments involved shall be available prior to the test. Recalibration shall be made after the test for those instruments of primary importance which are liable to variations or change as a result of test use. Any change of the instrument calibrations which will result in more than ± 2 percent in any calculated quantity may be cause for rejection of the test. See also Table 1, note 4.

3.17 Records and Test Report. Only such observations and measurements need be made as apply and are necessary to obtain the object of the test. Instrument indications or readings shall be recorded as observed. Original log sheets shall remain in the custody of the engineer in charge of the test. Copies of all original log sheets shall be furnished to each of the interested parties to the test. Corrections and corrected values shall be entered separately according to the "Report of Tests, Section 6."

(See next page for Table 1.)

TABLE 1

Variable	Permissible Deviation from Established Conditions[6]	Maximum Variation During Test[5]
Motive-fluid pressure[1]		± 5% during capacity tests ± 1% during stability tests
Motive-fluid quality or superheat[1,2]	25°F of superheat	± 5°F
Inlet-water temperature	-5°F, +0	± 2°F
Quantity of cooling water	-0, +5%	± 2%
Suction pressure[4]		± 1% Hg column ± 2% oil manometer
Suction temperature[3]	300°F	± 10°F
Discharge pressure[4]		± 2%
Flow-nozzle pressure (suction fluid)		± 1%
Flow-nozzle temperature[2] (suction fluid)		± 10°F

[1] When motive-fluid temperature is higher than design value, the motive-fluid pressure shall be increased by an amount sufficient to maintain specified flow when contract is based on zero initial superheat. Maximum deviation to be 15 percent of the design motive fluid pressure.
[2] If the motive fluid is specified dry-and-saturated it must be 100 percent quality; up to 25°F superheat is acceptable to insure dryness without being considered as a deviation from established conditions.
[3] This Code provides a temperature correction to capacity for suction fluids of air or steam only. See also 5.13.
[4] Below 5 mm see Table 2, Section 4.
[5] There shall be no rapid fluctuations during testing (frequency less than 30 sec).
[6] Conditions established by written agreement prior to testing.

SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

4.01 Test Arrangements. The essential requirements for testing ejector system stages or complete ejector systems are shown schematically in Fig. 1 through Fig. 3. The necessary control valves, the location of measuring stations, and the facilities for control of motive-fluid conditions are indicated. The test set-up shall provide suitable means for the establishment of uniform velocities at the ejector suction inlet. The inside diameter of the pipe connecting the air-measuring apparatus to the ejector shall not be less than that of the ejector suction inlet. The test arrangement will fall into one of the following categories:

(a) *Single-Stage Ejector*
A single-stage ejctor shall be tested as indicated in Fig. 1.

(b) *Noncondensing Multi-Stage Ejector System*
A noncondensing ejector system shall be tested as a complete system. The essential requirements for test of a complete noncondensing ejector system are given in Fig. 2 which shows a two-stage noncondensing system. Additional ejector stages shall be installed in a like manner with similar provisions for temperature and pressure measurements.

(c) *Multi-Stage Condensing Ejector System*
A multi-stage condensing ejector system may be tested as a complete system or tests may be conducted on individual stages or groups of stages.

(i) The test of a complete multi-stage condensing ejector system will involve one or more condensers which will require facilities for the control and measurement of cooling water. The essential requirements of an ejector system using surface or direct-contact condensers are shown in Fig. 3. This diagram shows two ejector stages with a single condenser. Additional ejector stages and condensers would be installed in a like manner with similar pressure and temperature stations.

(ii) The test set-up of an individual ejector stage will be similar to that of a single-stage ejector as shown in Fig. 1. The ejector may discharge directly into a condenser (which may be part of the system or an auxiliary vacuum source) without a control valve, provided the condenser pressure can be accurately regulated by an air bleed or by other means. The ejector discharge pressure in this case shall be measured at the condenser vapor-inlet nozzle.

(iii) Noncondensing stages of a multi-stage condensing ejector system shall be tested as a unit which may discharge to a condenser as described in paragraph (c)(ii). The essential requirements of the test set up are shown in Fig. 2 for a noncondensing ejector system.

4.02 Instrumentation. The selection of instruments, the methods of use and the precautions pertaining thereto are described herein. The Performance Test Code Supplements on Instruments and Apparatus (PTC 19 series) provides authoritative general information on instruments and their use and may be consulted for such information. Instrument calibration shall be in accordance with 3.16. The instruments and measuring apparatus which may be required for a Code test are listed below:

(a) Barometers (PTC 19.2).
(b) Thermometers and/or thermocouples (PTC 19.3).
(c) Bourdon-type pressure gages, U-tube manometers, absolute vacuum gages and differential-pressure gages (PTC 19.2).
(d) Fluid meters and measuring tanks ("Fluid Meters," sixth edition).
(e) Gas-analyzing apparatus (PTC 19.10).

Only those instruments necessary for attainment of the desired objective need be used.

Caution should be exercised with the use of mercury in measuring instruments due to potential health and/or material hazards involved.

4.03 Capacity Measurements. The capacity of single-stage or multiple-stage noncondensing ejectors should be determined with dry air and/or steam. However, if agreeable to both parties, other fluids may be used provided that their physical and thermodynamic properties are completely and reliably known. The measurement shall be made using subcritical or critical-flow devices as described in "Fluid Meters," which must be consulted for precise coefficients, mounting arrangements, and pressure-tap locations. Typical arrangements are shown in Fig. 4. For convenience, the flow formulae for flow nozzles (most commonly used) have been simplified for air and steam and are contained in Section 5.

4.04 If more than one suction fluid is involved simultaneously, a suitable mixing tank is required as shown in Fig. 5.

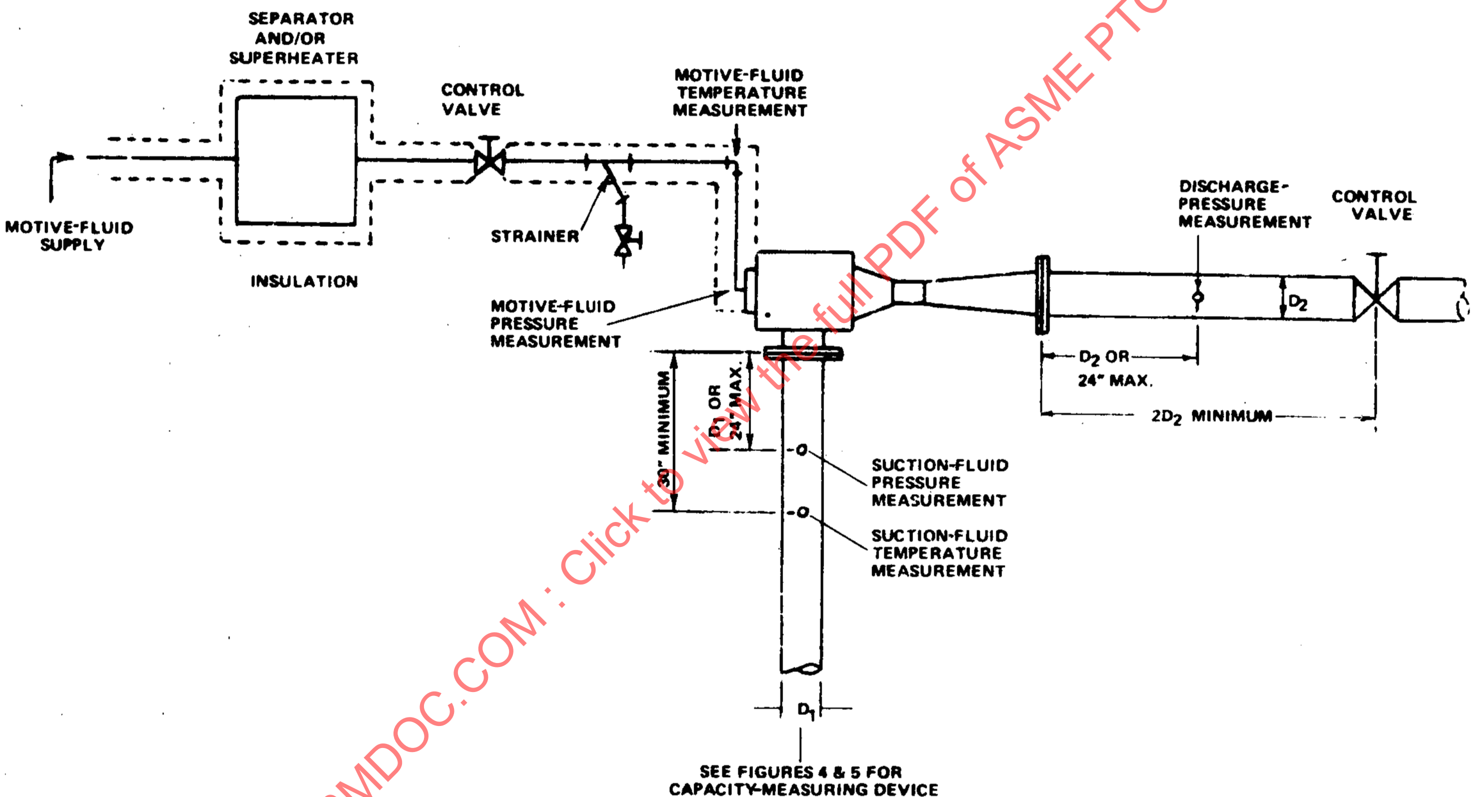

FIG. 1 DIAGRAM OF TEST ARRANGEMENT FOR A SINGLE-STAGE EJECTOR

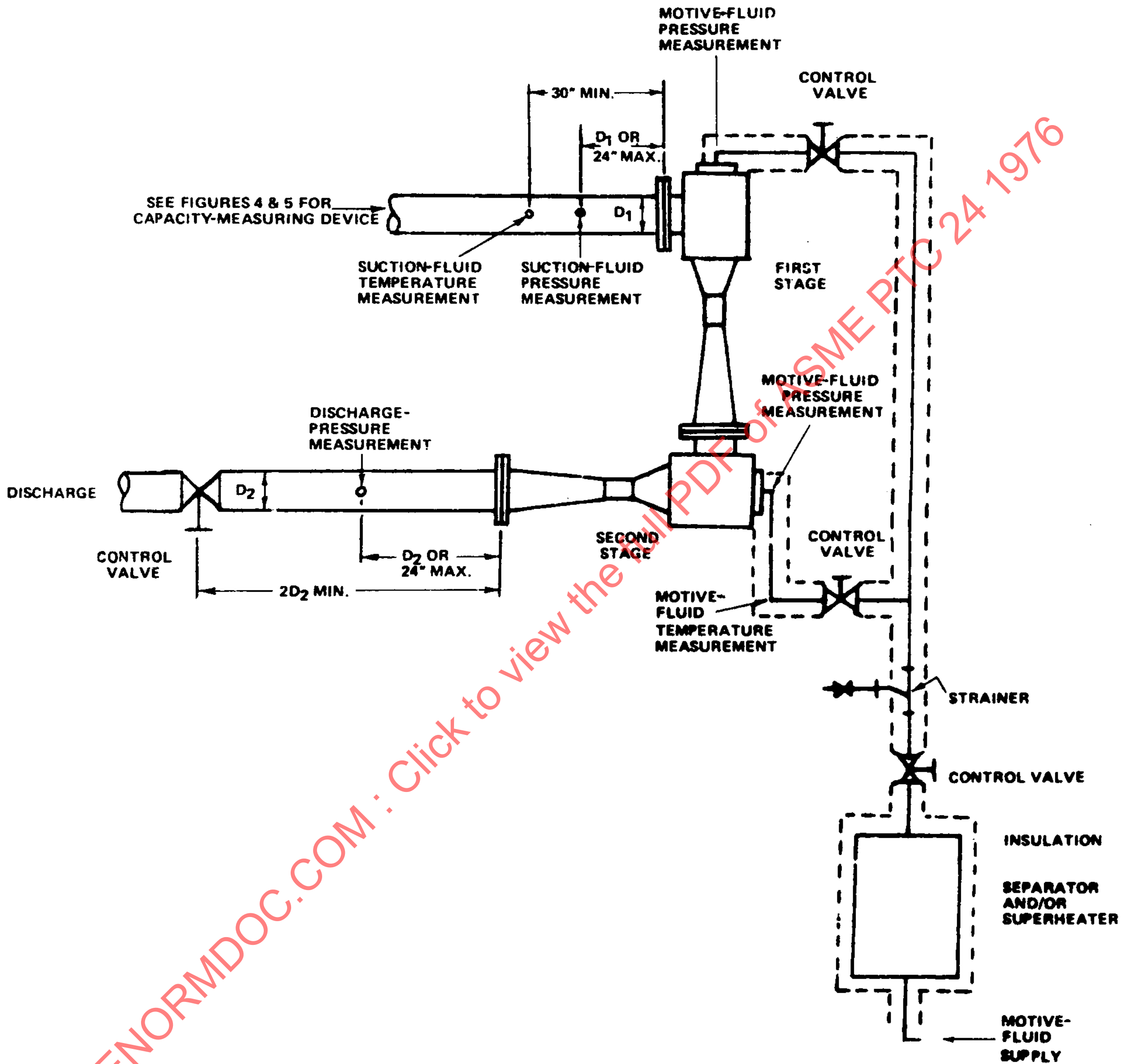

FIG. 2 DIAGRAM OF TEST ARRANGEMENT FOR A MULTI-STAGE NONCONDENSING EJECTOR SYSTEM

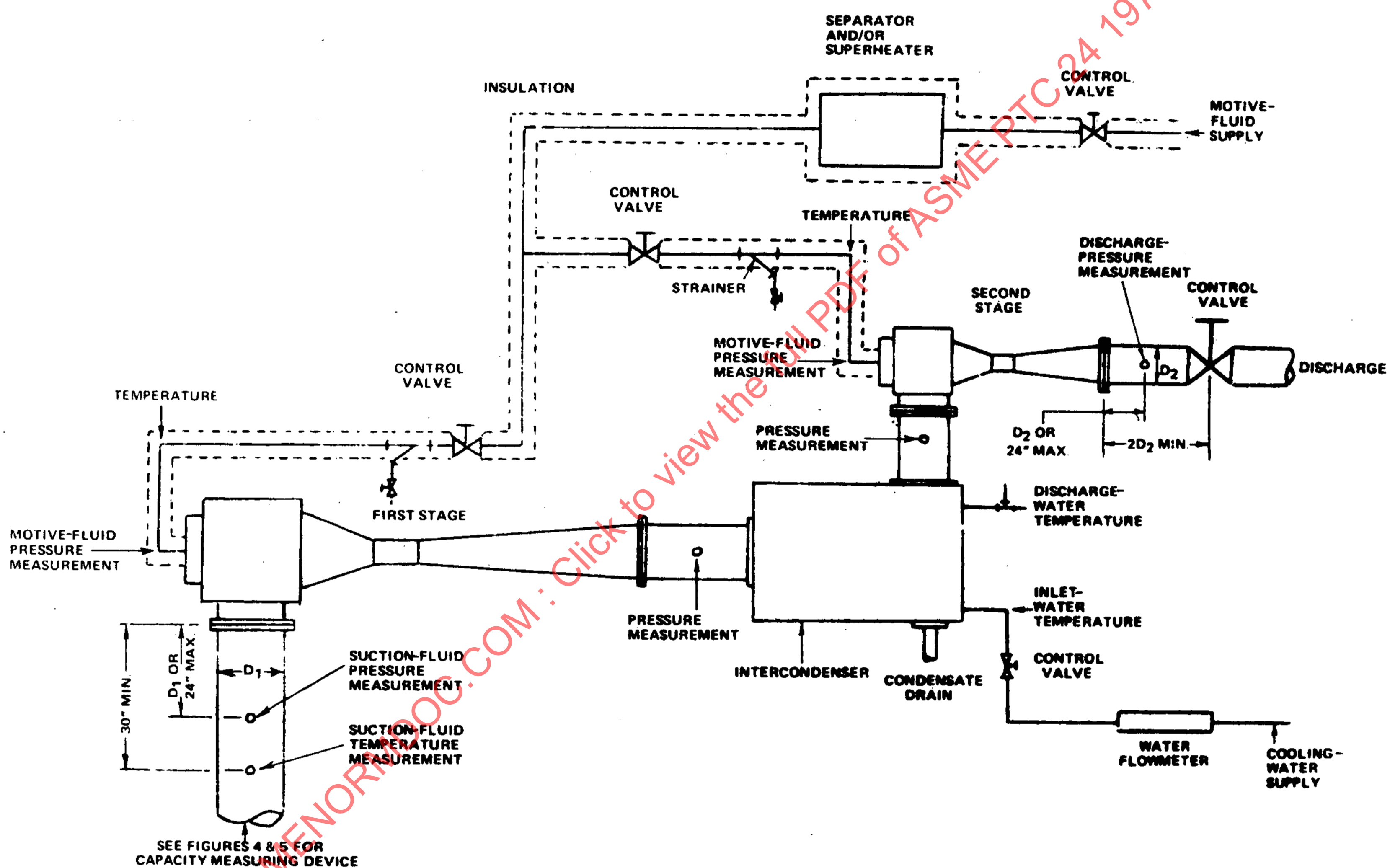

FIG. 3 DIAGRAM OF TEST ARRANGEMENT FOR A MULTI-STAGE CONDENSING EJECTOR SYSTEM

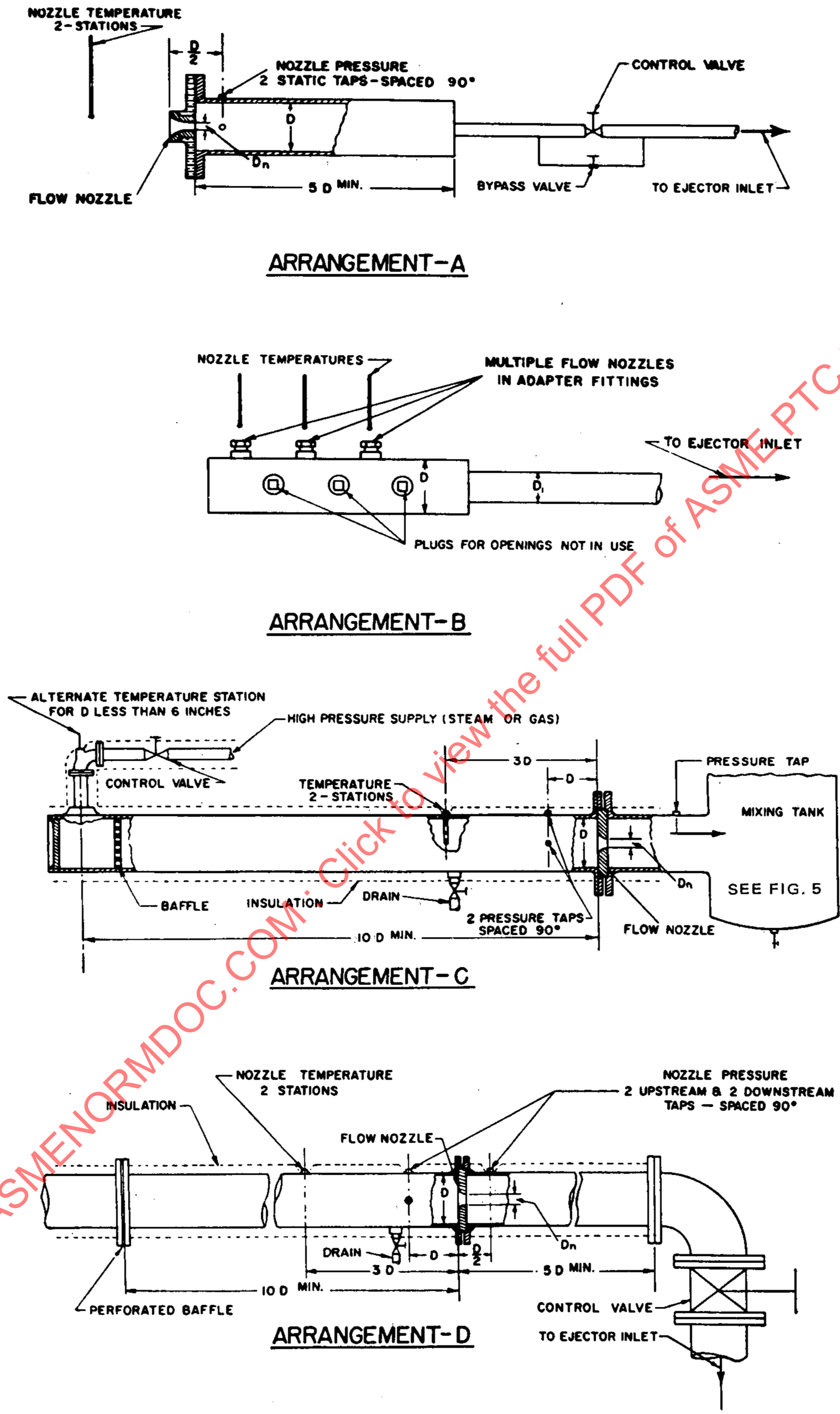

FIG. 4 FLOW-NOZZLE ARRANGEMENT

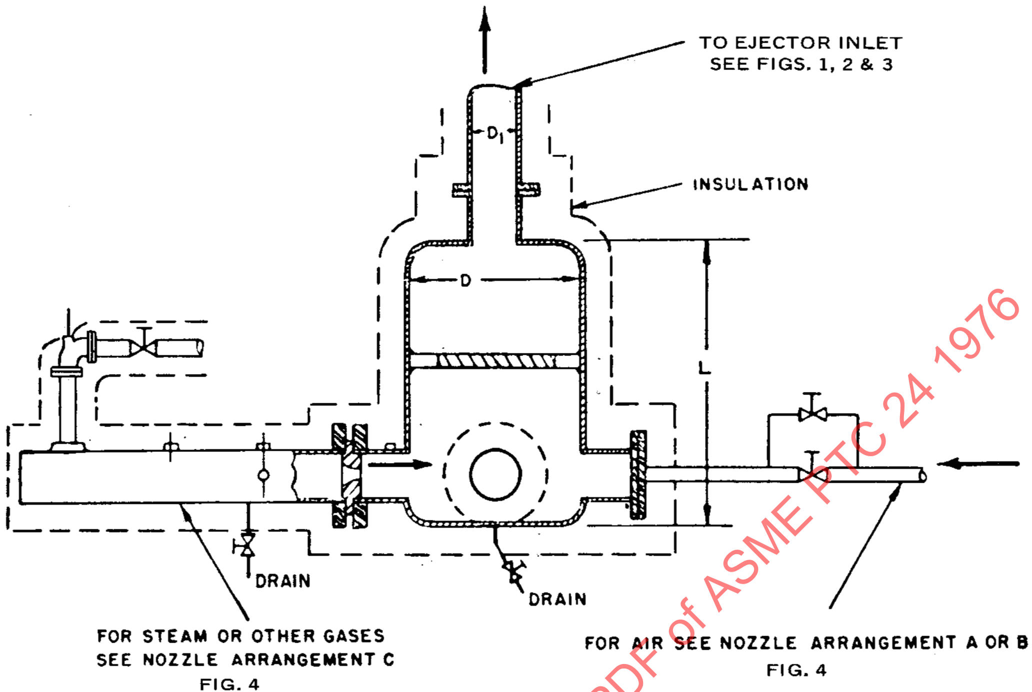

FIG. 5 ARRANGEMENT OF MIXING TANK

4.05 When steam is used as the motive fluid, the calculated capacity figures can be corrected for molecular weight and temperature for comparison with the design capacity (see Par. 5.13 and 5.15). However, if the motive fluid is not steam then the magnitude of the molecular weight and temperature corrections must be reached by agreement between the parties to the test.

4.06 The capacity of multiple-stage ejectors with inter-condensers shall be measured using only those fluids specified since the condenser performance could change significantly when substitute fluids are used. It is recommended, therefore, that when this type of a test is to be carried out, the specified capacity be expressed in terms of air and/or water vapor. If the capacity is to be measured with fluids other than air or water vapor, the physical and thermodynamic properties of these fluids must be completely and reliably known.

4.07 When the capacity of a multiple-stage ejector with inter-condensers is to be determined using substitute fluids, each stage or group of noncondensing stages shall be tested separately. Mutually agreed-to calculations and adjustments in test conditions shall be made to establish the performance of the condensers so that the capacity and necessary suction pressure of the ejector following the condenser can be accurately determined.

4.08 The expected overall accuracy of capacity measurement shall be computed using the methods described in "Fluid Meters," Part II, sixth edition.

4.09 Barometric-Pressure Measurement. Atmospheric pressure shall be measured with a mercury barometer of the Fortin type. The instrument shall be fitted with a vernier suitable for precise reading and shall have attached a thermometer for indicating the instrument temperature. It shall be located close to the test setup and supported on a structure free from mechanical vibration. Where the use of mercury is prohibited an acceptable substitute may be used.

4.10 The barometer shall be read at uniform intervals throughout the test period. The temperature of the instrument shall also be recorded.

4.11 Corrections shall be made for ambient temperature, elevation and for capillary depression if necessary in accordance with PTC 19.2 (Instruments and Apparatus), 1964 edition.

4.12 Suction and Discharge Pressure Measurements. Suction and discharge pressures shall be measured with the appropriate primary-standard gage as listed in Table 2. Other types of gages may be used if all of the following conditions are met:

(a) Agreement by both parties.
(b) Readability at least as good as the primary standard.
(c) The gage is calibrated against the primary standard before and after test runs.

4.13 Where primary gages do not read continuously or where contamination of the primary gage is likely, other gages shall be used in conjunction with the primary instruments to show pressure fluctuations.

4.14 Elastic gages shall have a guaranteed maximum error of 1.0 percent of their full-scale reading. Detailed instructions as to the use of such gages are given in PTC 19.2, Chapter 5.

4.15 The additional instructions and precautions concerning pressure connections covered in PTC 19.2, Chapter 2, shall be reviewed by both parties prior to testing; both parties agreeing that instructions and precautions have been adhered to.

4.16 **Temperature Measurement.** Techniques for measuring temperature are fully described in PTC 19.3. Selection of the type of instrument shall be made to accommodate the operating conditions, or convenience.

4.17 The instruments shall be sensitive, accurate and readable within 1.0 percent of the operating temperature. The operating range shall be suitable for the temperature to be measured.

4.18 The temperature-measuring device shall be installed in a flowing stream of the fluid being measured, and so located that no significant quantity of heat shall be transferred to it by radiation or conduction other than that of the medium being measured.

4.19 **Suction Temperature.** It is very difficult to measure accurately the temperature of low mass flows, such as the vapors entering an ejector suction. Whenever possible this temperature shall be calculated from the conditions existing ahead of the measuring flow nozzle.

4.20 For air or other "perfect" gases, the temperature shall be measured upstream from the measuring flow meter. This temperature shall be used as the temperature entering the ejector suction. The change in temperature due to expansion across the flow nozzle is insignificant.

TABLE 2

Measurement Range	Primary-Standard Gage	Readability	Minimum Connection-Tubing Bore, In.	Pressure-Tap Minimum Size, in.	Gage-Tube Minimum Bore, In.
15 psig & above	Elastic gages	1/2% full scale	1/4	1/16	–
0-15 psig	Mercury manometer or elastic gages	5 mm or 1/2% full scale	1/4	1/16	1/4
760-30 mm Hg abs	Mercury manometer	1 mm Hg	1/4	1/16	1/4
50-10 mm Hg abs	Mercury micro-manometer	0.2 mm Hg	5/16	1/16	3/8
30-2 mm Hg abs	Manometer* oil manometer	1 mm oil	5/16	1/8	–
10-1 mm Hg abs	McLeod** gage	0.02 mm Hg	5/16	1/8	–
1-0.1 mm Hg abs	McLeod** gage	0.002 mm Hg (2 microns)	3/8	1/4	–
0.1-0.01 mm Hg abs	McLeod** gage	0.0002 mm Hg (0.2 microns)	1/2	3/8	–

See PTC 19.2 – 1964 for instruments.
* Below 5.0 mm where electronic gages are in use, the accuracy must be specified and agreed to by parties of the test, taking into account the general problem of gage calibration, accuracy, suitability and affectation by fluids in the system.
**These gages are normally used in conjunction with electronic or other continuous-reading gages. The accuracy levels affectation by fluids in the system, etc., should be understood by both interested parties.

4.21 For steam or other fluids near saturation, the temperature shall be computed from the pressure and temperature existing ahead of the measuring flow nozzle using tabulated properties or a Mollier Chart at constant enthalpy.

4.22 For a mixture of air and steam the temperature shall be calculated as described in Section 5.12.

4.23 Motive-Fluid Temperature. The motive-fluid temperature shall be measured with a suitable device located as close as possible to the ejector and shall be down stream of any throttling or restricting devices.

4.24 Condenser-Coolant Temperature. The inlet and outlet condenser-coolant temperatures shall be measured when required with a suitable device, properly located to indicate true temperatures.

4.25 Motive-Fluid Flow Measurements. The flow rate of the motive fluid may be computed from observed pressures and temperatures. The formula for these computations is found in Section 5. However, this method may be used only when the motive fluid exhibits a single-phase upstream of the ejector nozzles (i.e., steam must be dry and saturated, or superheated).

4.26 Alternatively, the flow rate of steam or other condensable motive fluid may be measured by weighing the condensate collected in a surface condenser for a measured length of time. The measurement shall begin only after steady-state conditions have been recorded. During this measurement the ejector shall be operated with the suction connection blanked off and the pressure and temperature shall be maintained constant.

4.27 Motive-Fluid Pressure Measurements. The motive-fluid pressure shall be measured as close to the ejector nozzle as possible, care being taken to avoid line pressure drop and velocity effects from valves or elbows. Gages used shall be of the elastic type with a guaranteed maximum error of 1.0 percent of their full-scale reading. Detailed instructions as to the use of such gages are given in PTC 19.2, Chapter 5.

4.28 Condenser-Coolant Flow Measurement. Condenser-coolant flow rates may be measured using weigh tanks, volumetric tanks, area meters or differential-pressure meters. Measurements shall be made as prescribed in "Fluid Meters," to obtain an overall coolant flow-rate accuracy of ± 2.0 percent.

4.29 Operating Procedure. Preceding any test, all apparatus liable to leakage, particularly vacuum gage connections, shall be carefully checked and made tight.

4.30 The range of capacities suitable for test shall be determined in advance in accordance with the design or contract conditions. The ejector system shall be put into preliminary operation and loaded with fluid at any capacity within the determined range.

4.31 The preliminary operation shall continue until all adjustments of motive-fluid pressure, superheat, discharge pressure, and cooling water have been made. After temperatures have reached steady-state and all traces of wet steam are removed, the capacity shall be varied throughout the full determined range, and the stability of the ejector system observed. If the ejector is unstable, or gives evidence of improper operation, the cause shall be determined and corrected before proceeding with the test. Further, all liquids or frozen liquids deposited in the suction piping must also be removed before proceeding.

4.32 The Limit for Stable Operation. The limits for stable operation, in terms of motive-fluid pressure and discharge pressure, shall be determined before the final measurements of capacity are taken. These determinations shall be made with the ejector operated at each of several capacities within the determined range, with one point at the design suction pressure ± 5.0 percent. Stability may be determined by varying either the motive pressure or the discharge pressure as described in paragraphs 4.33 and 4.34.

4.33 Determination of Minimum Motive Pressure. The minimum motive pressure shall be determined as follows: with the capacity and discharge pressure held constant the motive pressure shall be lowered slowly until the ejector is "broken" (characterized by a sharp rise or fluctuations in the suction pressure); the motive pressure shall then be increased slowly until the suction pressure returns to its initial value or to a point where it is free from fluctuations and is not decreased by a further increase of motive pressure. The motive pressure at which this "recovery" occurs shall be taken as the minimum motive pressure. This observation should be repeated after temperatures have stabilized. During this test, the discharge pressure shall be maintained at the design value.

4.34 Determination of Maximum Discharge Pressure. The maximum discharge pressure shall be determined by procedures similar to those in Par. 4.33. While the motive pressure is held at the design value, the discharge pressure is slowly increased until the ejector is "broken." The discharge pressure is then slowly reduced until "recovery" occurs. The pressure at which recovery occurs is taken as the maximum discharge pressure.

4.35 For multi-stage noncondensing systems the stability tests outlined in Pars. 4.32, 4.33 and 4.34 are to be conducted on the system as a unit.

4.36 For multi-stage condensing systems, the stability tests above are to be conducted on the system as a unit, if the entire system is operating. However, if portions of the system are being tested separately, stability tests shall be required for each portion.

4.37 Final Capacity Measurements. Final capacity measurements may be made only after the stable operating values of motive and discharge pressure have been determined. The test shall be made only within the range of stable operation and the limits so noted.

4.38 A test to verify a single-point specification shall consist of not less than three capacity and stability points spaced to bracket the required capacity within ± 5 percent. If a characteristic curve is specified, a sufficient number of points shall be recorded to establish the performance of the ejector(s).

SECTION 5, COMPUTATIONS

5.01 A complete presentation of the performance of an ejector system shall include a statement of the following significant quantities:

(a) Capacity – naming motive-fluid used
(b) Suction pressure
(c) Suction temperature
(d) Discharge pressure – specifying if the reading is the recovery pressure
(e) Motive-fluid pressure – specifying if the reading is the recovery pressure
(f) Motive-fluid temperature
(g) Motive-fluid flow rate – naming fluid

If the system includes condensers, add the following:

(h) Cooling-water flow rate to each condenser
(i) Temperature of cooling water entering and leaving each condenser

The limiting conditions of stable operation shall also be given in terms of motive-fluid pressure and discharge pressure.

5.02 Before calculations are undertaken, the instrument readings, as recorded in the log, shall be scrutinized for inconsistency and fluctuation. Where the magnitude of fluctuation, or the deviation from the prescribed operating conditions is in excess of the limitations given in Table 1, the test point shall be rejected.

5.03 The average value of the readings of each instrument shall be computed and corrected by its calibration curve. Where more than one instrument is used for the same measurement, the corrected readings must be within the limits prescribed in Table 1 or the point shall be rejected.

5.04 The readings of pressure gages shall be corrected for the net effect of liquid head in the connecting tubing provided the tubing is full. There shall be no pockets of water in vapor tubing nor gas bubbles in liquid lines.

5.05 The specific weight of all manometer fluids shall be computed for the prevailing room temperature, and the pressure readings expressed in standard units. Manometer readings shall be adjusted for the differential expansion of the fluid and the scale.

5.06 Discharge coefficients to be used for the flow nozzles (including motive-fluid) shall have their source identified and agreed upon. For ASME long-radius nozzles, the values from "Fluid Meters," sixth edition, shall be used.

5.07 Flow Formula. The following simplified formulae shall be used for computing flow rates with nozzle arrangements provided in Section 4. They may be used only with gases where the physical properties do not vary, and are accurately known.

For subcritical flow where P_2 is more than 55 percent of P_1 for air or steam

$$m = \frac{1890\, F_a\, C d^2\, Y_a'}{(1-\beta^4)^{1/2}} \left[\rho_1 (P_1 - P_2)\right]^{1/2} \text{ lb/hr}$$

For metric units the constant 1890 becomes 3960

$$Y_a' = \left[\left(\frac{\gamma}{\gamma-1}\right) r^{(2/\gamma)} \left(\frac{1-r^{(\gamma-1)/\gamma}}{1-r}\right)\right]^{1/2} \left[\frac{1-\beta^4}{1-\beta^4 r^{(2/\gamma)}}\right]^{1/2}$$

(See Table 3 for Y_a' for air and steam.)

For critical flow where P_2 is less than 50 percent of P_1

$$m = 1890\, F_a C d^2\, Z' \quad (\rho_1\, P_1)^{1/2} \text{ lb/hr}$$

For metric units the constant 1890 becomes 3960

$$Z' = \left(\frac{2}{\gamma+1}\right)^{1/(\gamma-1)} \left(\frac{\gamma}{\gamma+1}\right)^{1/2} \frac{1}{\left[1-\left(\frac{2}{\gamma+1}\right)^{2/(\gamma-1)}\beta^4\right]^{1/2}}$$

(See also Fig. 10.)

A more exact formula for critical flow is that critical flow is present if

$$P_2 \leqslant P_{1_t}\left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$$

Where

	English	SI
m = flow rate	lb/hr	kg/hr
C = discharge coefficient		
D = diameter of pipe at upstream section	in.	cm
d = diameter of orifice in nozzle	in.	cm
P_1 = upstream static pressure	psia	kg/cm^2
P_2 = downstream static pressure	psia	kg/cm^2
r = P_2/P_1		
γ = C_p/C_v, ratio of specific heats		
β = ratio of nozzle orifice diameter to the pipe inside diameter, d/D		
ρ = density	lb/cu ft	gm/cc

For air $\rho_1 = 2.699\, P_1/T_1$ in English units or $\rho_1 = 0.3413\, P_1/T_1$ in Metric units where T_1 is the upstream temperature in absolute units. For steam, consult the 1967 ASME Steam Tables.

Y'_a = expansion factor at subcritical-flow conditions, a ratio

Z' = expansion factor at critical-flow conditions, a ratio

F_a = area multiplier for thermal expansion of nozzle

Note: Constants 1890 and 3960 are based on gravity constant, $g = 32.17$ ft/sec²

5.08 Total pressure P_{1_t} used in determining whether flow is critical or subcritical may be found directly with an impact tube or calculated as follows:

$$P_{1_t} = \frac{P_1}{\left[1 - \beta^4 \frac{\gamma}{2}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}\right]}$$

5.09 For tests using atmospheric air, the effect of humidity may be considered negligible for temperatures up to 100°F.

5.10 For air, the value of γ shall be taken as 1.4 under all flow conditions. For steam, γ may be taken as 1.3 for all steam conditions up to 200 psia and 600°F. Other values may be obtained from the steam tables for pressure and temperature conditions upstream of the nozzle.

5.11 Figure 7 may be used for the flow nozzle discharge coefficient obtained from

$$C = 0.9975 - 0.00653\,(10^6/Re)^{1/2}$$

Where Re is the Reynolds number expressed as

$$Re = \frac{m}{235.6\,\mu d}\ \text{English} \quad \text{or} \quad Re = \frac{35.3m}{\mu d}\ \text{SI}$$

μ = absolute viscosity in lb_m/ft sec in English units or centipoise for SI units

See Figs. 8 and 9 for viscosity of air and steam.

5.12 It is recommended that the value of β not exceed 0.25 for any flow measurements with sonic flow through metering nozzles.

5.13 The capacity of the ejector is sensitive to the suction temperature. Where the fluid being pumped is air or steam, capacity correction values to be used are shown in Fig. 11. In using this factor, note that an ejector will handle more lb/hr of a cool gas than a hot one.

Temperature correction factors are not available for suction fluids other than air or steam or for motive fluids other than steam.

5.14 If a mixture of air and steam is used as a suction fluid, the suction temperature, t_s, shall be computed as follows:

$$t_s = \frac{(m\,C_p\,t)_{air} + (m\,C_p\,t)_{steam}}{(m\,C_p)_{air} + (m\,C_p)_{steam}}$$

where

m = fluid rate in lb per hr (kg/hr)

Cp = heat capacity in Btu/lb °F (cal/gm°C)

t_A = air temperature upstream of flow nozzle in °F (°C)

t_{STM} = temperature calculated for steam pressure and temperature upstream of flow nozzle and expansion at constant enthalpy, °F (°C)

Note: Other than the motive-fluid nozzle, no flow nozzle shall have a diverging exit section.

5.15 For suction fluids of various molecular weights, the capacity shall be corrected, as shown in Fig. 12. The correction factor is well established for suction pressures above 10 mm Hg absolute. Use at lower pressures must be agreed to by the parties to the test. This curve is applicable for suction temperatures between 50 and 100°F. In its use, note that an ejector will handle more pounds per hour of a higher molecular weight fluid than of a lower one.

5.16 The capacity and stability at a single point shall be determined from a graphical plot, as illustrated by Fig. 6. Corrected capacity points are plotted and a curve drawn. The same applies to stability data. The respective scales on the curve shall be readable within ± 1.0 percent.

5.17 Measurement of Motive-Fluid Flow Rate. This is normally done by measuring the pressure and temperature upstream of the motive-fluid nozzle and using one of the formulae given under Section 5.07. The orifice diameter shall be measured by plug gages or other suitable means. The discharge coefficient for sonic flow is usually taken to be 0.97 for nozzles with well-rounded inlets; alternatively, Fig. 7 may be used. If the weighed condensate method is used, the suction-fluid rate shall be zero. An adequate surface condenser must be available. The minimum period of measurement shall be one-half hour, with not less than four consecutive readings made at uniform intervals. The data shall show that the motive pressure and temperature were held within 2.0 percent of the mean value.

5.18 Cooling-water rate shall be measured only by methods given in "Fluid Meters." Allowable variations are given in Table 1.

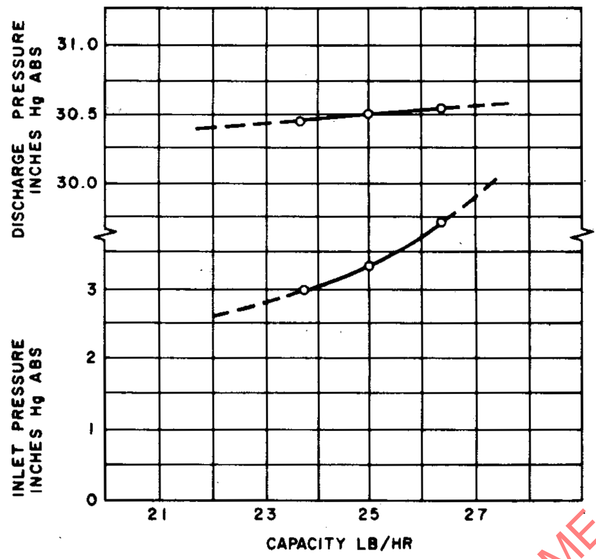

FIG. 6 CHARACTERISTIC CURVES FOR EJECTOR PERFORMANCE

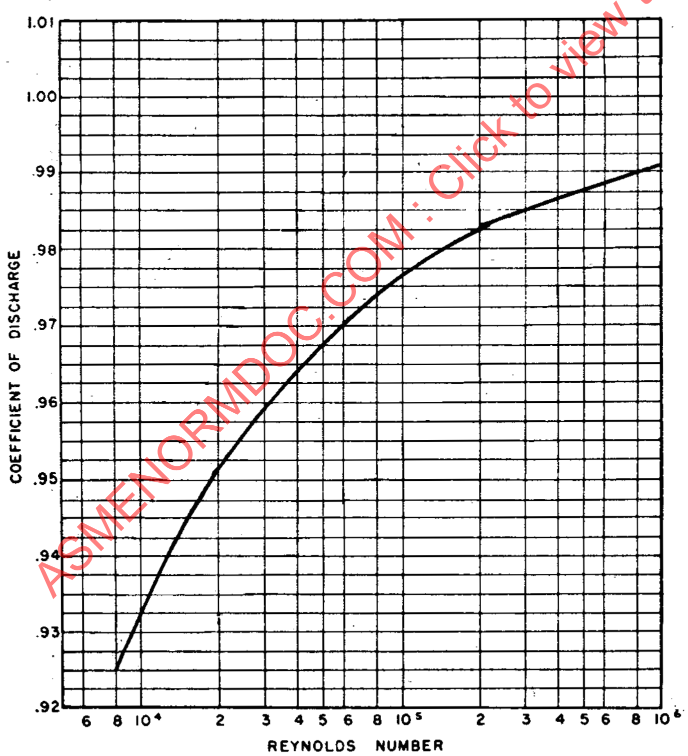

FIG. 7 NOZZLE DISCHARGE COEFFICIENT

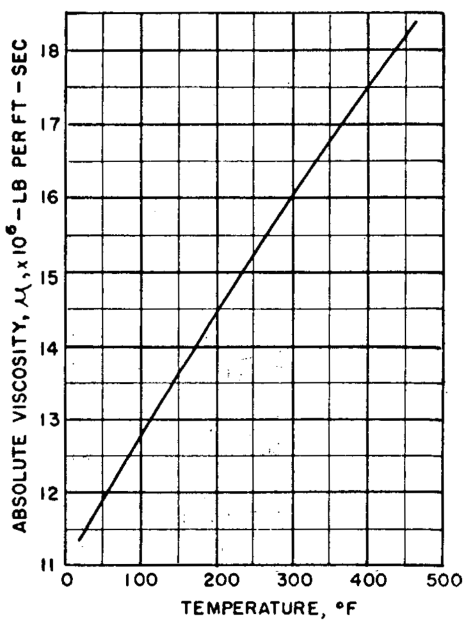

FIG. 8 ABSOLUTE VISCOSITY OF AIR

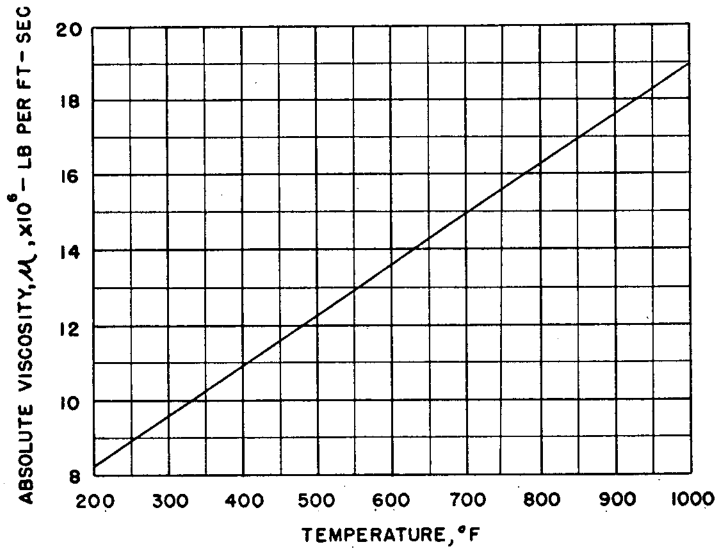

FIG. 9 ABSOLUTE VISCOSITY OF STEAM

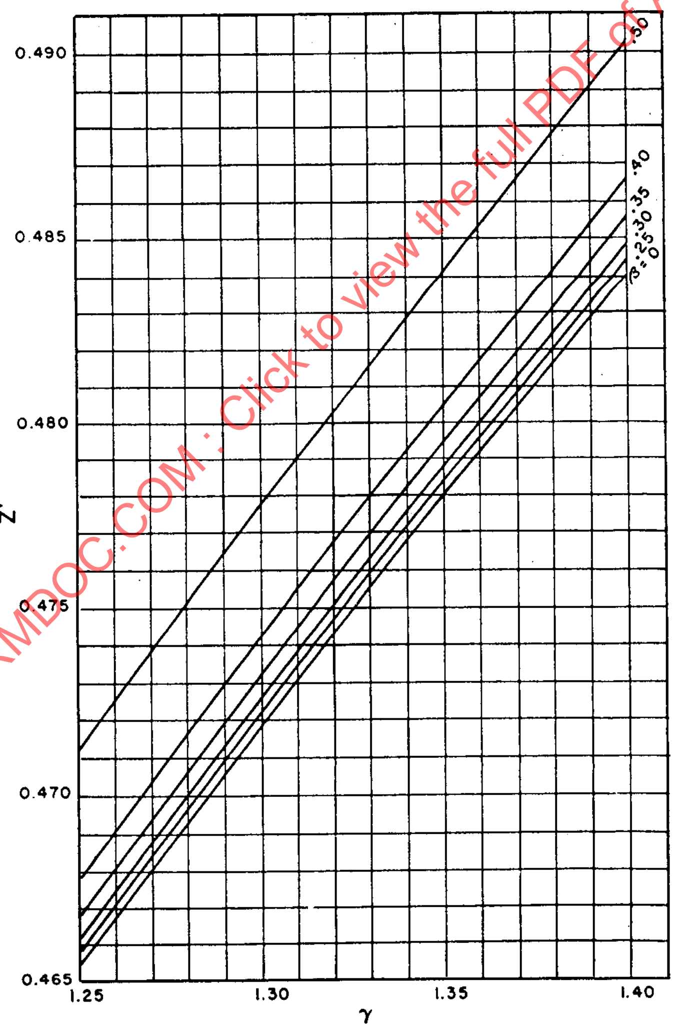

FIG. 10 FLOW FACTOR Z' FOR CRITICAL FLOW

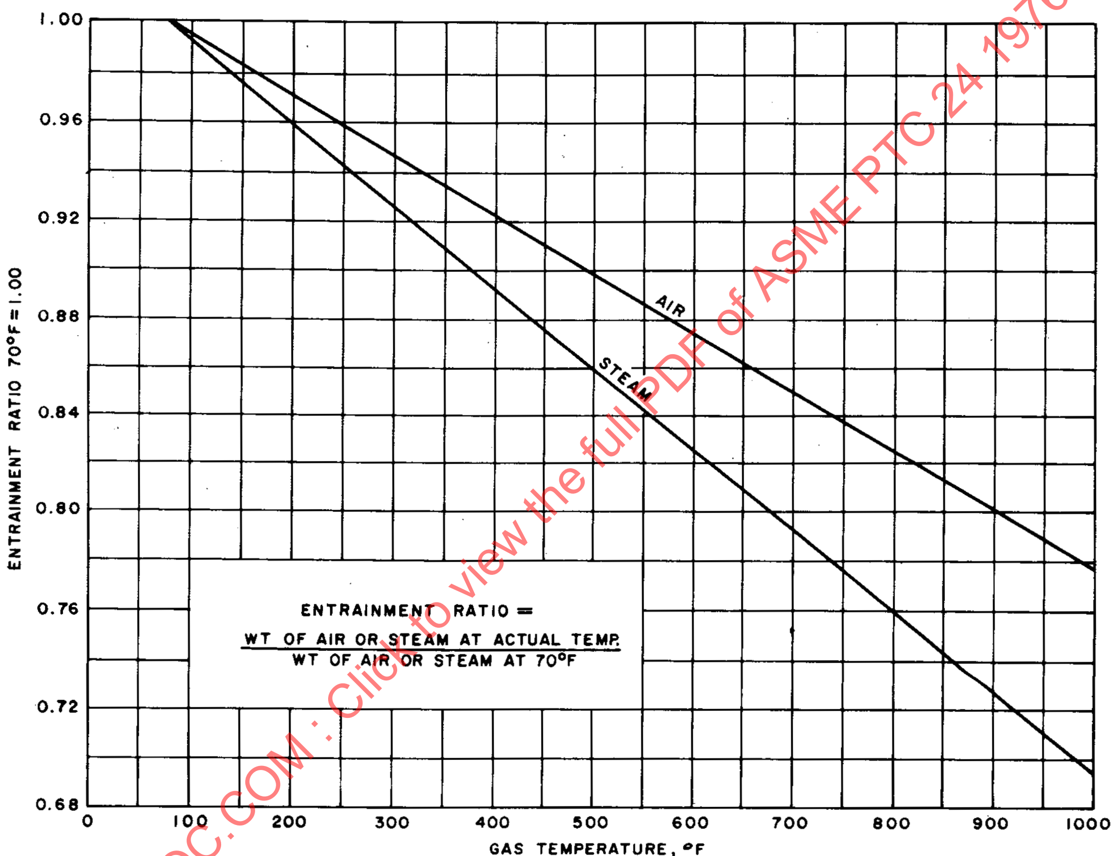

FIG. 11 TEMPERATURE ENTRAINMENT RATIO CURVE

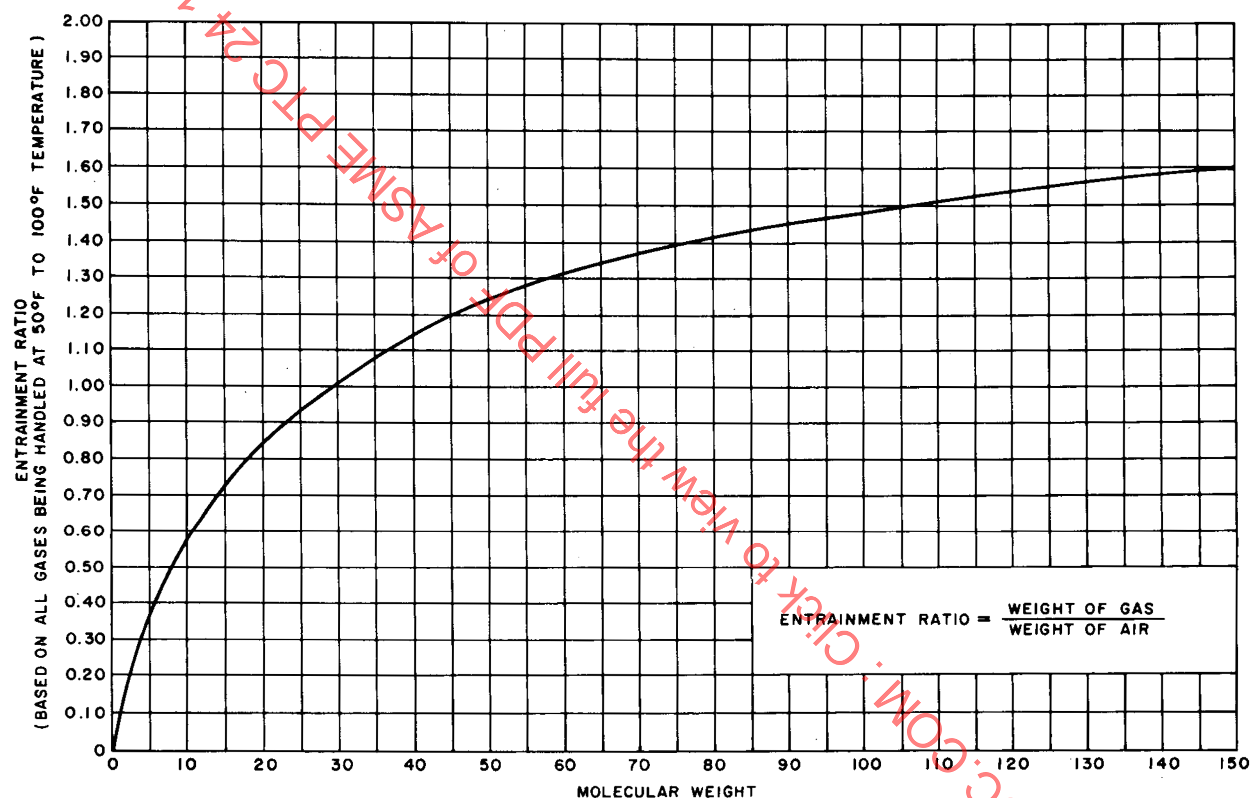

FIG. 12 MOLECULAR WEIGHT ENTRAINMENT RATIO CURVE