

AICHE

EQUIPMENT TESTING PROCEDURE

EVAPORATORS

 **SECOND**

EDITION



AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

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AIChE Equipment Testing Procedure

Evaporators

A Guide to Performance Evaluation

Second Edition

**Prepared by the
Equipment Testing Procedures Committee**

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**American Institute of Chemical Engineers
345 East 47 Street, New York, N.Y. 10017**

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*This Table is included to facilitate conversion to AIChE metric units. The procedure is written in English units.

AIChE Goes Metric

INSTITUTE ACTION

Beginning in 1979, the International System of Units (SI) will be used in all Institute publications, meeting papers, and course texts.

J. Y. Oldshue, Mixing Equipment Co., Inc., Rochester, N.Y.

Schedules for AIChE entering into metric conversion using SI were determined by the AIChE Council at their March, 1977, meeting in Houston, Tex., based on recommendations from the Metrication Committee. The key point is that every paper submitted for presentation in an AIChE meeting, or submitted for publication in an AIChE journal, or any new course text submitted for presentation at an AIChE-sponsored course after January 1, 1979, must use SI units. Other units, such as Centimeter-Gram-Second (CGS) Metric, or English, may be used in addition, although this practice is discouraged.

On the accompanying pages is a guide to SI, including tables of conversion, which will be made available in quantity to all AIChE committees and divisions that need it.

SI is somewhat different than the CGS system, in use for many years, which has often been called the Metric System. SI is a system adopted internationally by the General Conference on Weights and Measures. Among some of the principles are the use of the kilogram for mass only, and the use of newton for force.

Pressure is expressed in terms of newtons per square meter, and is given the name, pascal. The pascal is a very small unit, and the kilopascal is suggested as the most common unit for pressure.

The main feature of SI is in the fact that it is coherent, which means that no conversion factors are needed when using basic or derived SI units. Any exception to the SI units destroys the coherency of the system, and is not really a step forward in usefulness.

The third column of Table 1 shows the metric units that may be used for an indefinite period of time with SI. These include the minute, hour, year, and liter. The fourth column contains units that are accepted for a limited period of time, probably on the order of five to 10 years, although this duration has not been established by the Institute. And finally, the fifth column lists those units that are definitely outside SI, and which will not be allowed in AIChE publications.

In the opinion of the Metrication Committee, there is no longer any question about eventual conversion to the metric system, and to SI in particular. The only question really is, when and how? AIChE is following the practice being instituted by many technical societies; we are not either leading or trailing significantly at present.

On the lighter side, the magnitude of the newton is about the weight of an apple. If we were to grind up that apple and spread it out over one square meter, we would have a pressure of one pascal, which may give a better feeling for the small size of that particular unit. Your Chairman of the Metrication Committee is approximately 2 meters tall, which was not a requirement, but can serve as a benchmark.

The Metrication Committee plans to submit a series of articles to CEP at two or three month intervals that will deal with various aspects of metric conversion. These are planned to include a typical process flow diagram in SI, a consideration of hard vs. soft conversion, consideration of conversion of various physical properties into SI, case histories of conversion in various industries and companies, and a description of the working of the International Standards Organizations.

Every AIChE committee and division has a member on the committee who acts as its liaison. Please feel free to call upon us for any assistance or information on conversion.

The Council resolution adopted National Bureau of Standards special publication 330, 1974 edition, entitled, "International System of Units (SI)." This is an official translation of the publication in French of the same title that was published by the International Bureau of Weights and Measures. In the last several months, there have been several American National Standards Institute publications on metric practices. The AIChE Committee is looking into adopting some of these or other publications, or preparing a separate, more detailed guide, if needed, on metric practice. In particular, the Institute of Electrical & Electronics Engineers' document, ANSI-Z210.1 - 1976 is accepted.

Table 1. Acceptable and unacceptable metric units.

Quantity	SI Unit	AIChE Recommendations		
		Accepted Alternate*	Temporary Alternate**	To Be Avoided†
Time	second	year day hour#		
Pressure	pascal		bar, atmosphere	kg force cm ²
Energy	joule	—	—	calorie kilowatt-hr.
Force	newton	—	—	dyne, kilogram
Mass	kilogram	metric ton	—	—
Volume	m ³	liter	—	—
Viscosity	Pa s	—	—	poise‡

*Table 8 NBS 330 **Table 10 NBS 330 †Tables 11 & 12 NBS 330

‡To be avoided because they were formerly used with the CGS system and are not part of SI.

#Not part of SI, but added by AIChE.

(REV., 1-1-78)

In addition, the American National Metric Council has published an editorial guide that contains much information for authors, editors, secretaries, and other people involved in publication. This is available through the American National Metric Council, 1625 Massachusetts Ave. N.W., Washington, D. C. 20036.

Note: Reprints of this article and guide will be made available to AIChE groups at no charge for Institute business purposes. Individuals interested in copies for their personal use may obtain the reprints for \$1.50 prepaid. In either case write: Publications Dept., AIChE, 345 E. 47 St., New York, N. Y., 10017.

A Word About the Guide

This guide for the use of SI units, originally published in the May, 1971, issue of CEP, has been updated and expanded slightly since then to conform to present practices. This material was prepared by Evan Buck, staff engineer, Union Carbide Corp., South Charleston, W. Va., a member of the Metrication Committee.



Oldshue



Buck

Abbreviated Guide for Use of the SI

These tables summarize the SI unit system adopted by the AIChE Council on March 19, 1977, for use within the AIChE after January 1, 1979. This unit system is based on that documented in the National Bureau of Standards (NBS) Special Publication 330, 1974 edition, titled "The International System of Units (SI)," with the following modifications:

1. The "year" as a time unit has been added.
2. The symbol "L" rather than "l" is to be used as the abbreviation for liter, which avoids possible confusion with the numeral "1."
3. The prefixes "peta" (10^{15}) and "exa" (10^{18}) have been added.

Items 2 and 3 have been adopted by the NBS subsequent to the appearance of Publication 330.

SI Base Units

Quantity	Name	Symbol
length.....	meter.....	m
mass.....	kilogram.....	kg
time.....	second.....	s
electric current.....	ampere.....	A
thermodynamic temperature.....	kelvin.....	K
amount of substance.....	mole.....	mol
luminous intensity.....	candela.....	cd

SI Supplementary Units

Quantity	Name	Symbol
plane angle.....	radian.....	rad
solid angle.....	steradian.....	sr

Examples of SI Derived Units Expressed in Terms of Base Units

SI Unit		
Quantity	Name	Symbol
area.....	square meter.....	m ²
volume.....	cubic meter.....	m ³
speed, velocity.....	meter per second.....	m/s
acceleration.....	meter per second squared.....	m/s ²
kinematic viscosity.....	square meter per second.....	m ² /s
wave number.....	1 per meter.....	m ⁻¹
density, mass density.....	kilogram per cubic meter.....	kg/m ³
current density.....	ampere per square meter.....	A/m ²
magnetic field strength.....	ampere per meter.....	A/m
concentration (of amount of substance).....	mole per cubic meter.....	mol/m ³
activity (radioactive).....	1 per second.....	s ⁻¹
specific volume.....	cubic meter per kilogram.....	m ³ /kg
luminance.....	candela per square meter.....	cd/m ²
angular velocity.....	radian per second.....	rad/s
angular acceleration.....	radian per second squared.....	rad/s ²

SI Derived Units With Special Names

SI Unit			Expression in terms of other units
Quantity	Name	Symbol	
frequency.....	hertz.....	Hz	s ⁻¹
force.....	newton.....	N	kg · m/s ²
pressure, stress.....	pascal.....	Pa	N/m ²
energy, work, quantity of heat.....	joule.....	J	N · m
power, radiant flux.....	watt.....	W	J/s
quantity of electricity, electric charge.....	coulomb.....	C	A · s
electric potential, voltage, potential difference, electromotive force.....	volt.....	V	W/A
capacitance.....	farad.....	F	C/V
electric resistance.....	ohm.....	Ω	V/A
conductance.....	siemens.....	S	A/V
magnetic flux.....	weber.....	Wb	V · s
magnetic flux density.....	tesla.....	T	Wb/m ²
inductance.....	henry.....	H	Wb/A
luminous flux.....	lumen.....	lm	cd · sr
illuminance.....	lux.....	lx	cd · sr/m ²

Examples of SI Derived Units Expressed by Means of Special Names

SI Unit

Quantity	Name	Symbol
dynamic viscosity	pascal-second	Pa · s
moment of force	meter-newton	N · m
surface tension	newton per meter	N/m
heat flux density, irradiance	watt per square meter	W/m ²
heat capacity, entropy	joule per kelvin	J/K
specific heat capacity, specific entropy	joule per kilogram-kelvin	J/(kg · K)
specific energy	joule per kilogram	J/kg
thermal conductivity	watt per meter-kelvin	W/(m · K)
energy density	joule per cubic meter	J/m ³
electric field strength	volt per meter	V/m
electric charge density	coulomb per cubic meter	C/m ³
electric flux density	coulomb per square meter	C/m ²
permittivity	farad per meter	F/m
permeability	henry per meter	H/m
molar energy	joule per mole	J/mol
molar entropy, molar heat capacity	joule per mole-kelvin	J/(mol · K)
radiant intensity	watt per steradian	W/sr
radiance	watt per square meter-steradian	W · m ⁻² · sr ⁻¹

Units in Use With the International System

Name	Symbol	Value in SI Units
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 86400 s
year	yr	1 yr ≈ 365 d
degree	°	1° = (π/180) rad

Name	Symbol	Value in SI Units
minute	'	1' = (1/60)° = (π/10800) rad
second	"	1" = (1/60)' = (π/648000) rad
liter	L	1 L = 1 dm ³ = 10 ⁻³ m ³
metric ton	t	1 t = 10 ³ kg
nautical mile		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
ångström	Å	1 Å = 0.1 nm = 10 ⁻¹⁰ m
are	a	1 a = 1 dam ² = 10 ² m ²
hectare	ha	1 ha = 1 hm ² = 10 ⁴ m ²
barn	b	1 b = 100 fm ² = 10 ⁻²⁸ m ²
bar	bar	1 bar = 0.1 MPa = 10 ⁵ Pa
standard atmosphere	atm	1 atm = 101325 Pa
gal	Gal	1 Gal = 1 cm/s ² = 10 ⁻² m/s ²
curie	Ci	1 Ci = 3.7 × 10 ¹⁰ s ⁻¹
röntgen	R	1 R = 2.58 × 10 ⁻⁴ C/kg
rad	rad	1 rad = 10 ⁻² J/kg

Note: In addition to the thermodynamic temperature (symbol *T*), expressed in kelvins, use is also made of Celsius temperature (symbol *t*) defined by the equation

$$t = T - T_0$$

where $T_0 = 273.15$ K by definition. The Celsius temperature is expressed in degrees Celsius (symbol °C). The unit "degree Celsius" is thus equal to the unit "kelvin," and an interval or a difference of Celsius temperature may also be expressed in degrees Celsius.

SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10 ¹⁸	exa	E	10 ⁻¹	deci	d
10 ¹⁵	peta	P	10 ⁻²	centi	c
10 ¹²	tera	T	10 ⁻³	milli	m
10 ⁹	giga	G	10 ⁻⁶	micro	μ
10 ⁶	mega	M	10 ⁻⁹	nano	n
10 ³	kilo	k	10 ⁻¹²	pico	p
10 ²	hecto	h	10 ⁻¹⁵	femto	f
10 ¹	deka	da	10 ⁻¹⁸	atto	a

Directions for Use

SI symbols are not capitalized unless the unit is derived from a proper name; e.g., Hz for H. R. Hertz. Unabbreviated units are not capitalized; e.g., hertz, newton, kelvin. Only E, P, T, G, and M prefixes are capitalized.

Except at the end of a sentence, SI units are not to be followed by periods.

In derived unit symbols, use center dot to denote multiplication and a slash for division; e.g., newton-second per square meter = N · s / m².

Conversion Factors to SI for Selected Quantities

*An asterisk after the seventh decimal place indicates the conversion factor is exact and all subsequent digits are zero.

To convert from	To	Multiply by
barrel (for petroleum, 42 gal)	meter ³ (m ³)	1.5898729 E - 01
British thermal unit (Btu, International Table)	joule (J)	1.0550559 E + 03

Continued

To convert from	To	Multiply by
Btu/1bm-deg F (heat capacity)	joule/kilogram-kelvin (J/kg·K)	4.1868000* E + 03
Btu/hour	watt (W)	2.9307107 E - 01
Btu/second	watt (W)	1.0550559 E + 03
Btu/ft ² -hr-deg F (heat transfer coefficient)	joule/meter ² -second-kelvin (J/m ² ·s·K)	5.6782633 E + 00
Btu/ft ² -hour (heat flux)	joule/meter ² -second (J/m ² ·s)	3.1545907 E + 00
Btu/ft-hr-deg F (thermal conductivity)	joule/meter-second-kelvin (J/m·s·K)	1.7307347 E + 00
calorie (International Table)	joule (J)	4.1868000* E + 00
calorie (Thermochemical)	joule (J)	4.1840000* E + 00
cal/g·deg C	joule/kilogram-kelvin (J/kg·K)	4.1868000* E + 03
centimeter	meter (m)	1.0000000* E - 02
centimeter of mercury (0°C)	pascal (Pa)	1.3332237 E + 03
centimeter of water (4°C)	pascal (Pa)	9.80638 E + 01
centipoise	pascal-second (Pa·s)	1.0000000* E - 03
centistokes	meter ² /second (m ² /s)	1.0000000* E - 06
degree Fahrenheit (°F)	kelvin (K)	$t_K = (t_F + 459.67)/1.8$
degree Rankine (°R)	kelvin (K)	$t_K = t_R/1.8$
dyne	newton (N)	1.0000000* E - 05
erg	joule (J)	1.0000000* E - 07
farad (International of 1948)	farad (F)	9.99505 E - 01
fluid ounce (U.S.)	meter ³ (m ³)	2.9573530 E - 05
foot	meter (m)	3.0480000* E - 01
foot (U.S. Survey)	meter (m)	3.0480061 E - 01
foot of water (39.2°F)	pascal (Pa)	2.98898 E + 03
foot ²	meter ² (m ²)	9.2903040* E - 02
foot/second ²	meter/second ² (m/s ²)	3.0480000* E - 01
foot ² /hour	meter ² /second (m ² /s)	2.5806400* E - 05
foot-pound-force	joule (J)	1.3558179 E + 00
foot ² /second	meter ² /second (m ² /s)	9.2903040* E - 02
foot ³	meter ³ (m ³)	2.8316847 E - 02
gallon (U.S. liquid)	meter ³ (m ³)	3.7854118 E - 03
gram	kilogram (kg)	1.0000000* E - 03
horsepower (550 ft·lbf/s)	watt (W)	7.4569987 E + 02
inch	meter (m)	2.5400000* E - 02
inch of mercury (60°F)	pascal (Pa)	3.37685 E + 03
inch of water (60°F)	pascal (Pa)	2.48843 E + 02
inch ²	meter ² (m ²)	6.4516000* E - 04
inch ³	meter ³ (m ³)	1.6387064* E - 05
kilocalorie	joule (J)	4.1868000* E + 03
kilogram-force (kgf)	newton (N)	9.8066500* E + 00
micron	meter (m)	1.0000000* E - 06
mil	meter (m)	2.5400000* E - 05
mile (U. S. Statute)	meter (m)	1.6093440* E + 03
mile/hour	meter/second (m/s)	4.4704000* E - 01
millimeter of mercury (0°C)	pascal (Pa)	1.3332237 E + 02
ohm (International of 1948)	ohm (Ω)	1.000495 E + 00
ounce-mass (avoirdupois)	kilogram (kg)	2.8349523 E - 02
ounce (U. S. fluid)	meter ³ (m ³)	2.9573530 E - 05
pint (U. S. liquid)	meter ³ (m ³)	4.7317647 E - 04
poise (absolute viscosity)	pascal-second (Pa·s)	1.0000000* E - 01
poundal	newton (N)	1.3825495 E - 01
pound-force (lbf)	newton (N)	4.4482216 E + 00
pound-force-second/ft ²	pascal-second (Pa·s)	4.7880258 E + 01
pound-mass (lbm avoirdupois)	kilogram (kg)	4.5359237* E - 01
pound-mass/foot ³	kilogram/meter ³ (kg/m ³)	1.6018463 E + 01
pound-mass/foot-second	pascal-second (Pa·s)	1.4881639 E + 00
psi	pascal (Pa)	6.8947573 E + 03
quart (U. S. liquid)	meter ³ (m ³)	9.4635295 E - 04
slug	kilogram (kg)	1.4593903 E + 01
stokes (kinematic viscosity)	meter ² /second (m ² /s)	1.0000000* E - 04
ton (long, 2240 lbm)	kilogram (kg)	1.0160469 E + 03
ton (short, 2000 lbm)	kilogram (kg)	9.0718474* E + 02
torr (mm Hg, 0°C)	pascal (Pa)	1.3332237 E + 02
volt (International of 1948)	volt (absolute) (V)	1.000330 E + 00
watt (International of 1948)	watt (W)	1.000165 E + 00
watt-hour	joule (J)	3.6000000* E + 03
yard	meter (m)	9.1440000* E - 01

A.I.Ch.E. TESTING PROCEDURE FOR EVAPORATORS

100.0 PURPOSE AND SCOPE

101.0 Purpose

101.1 This testing procedure provides methods of conducting and interpreting performance tests on evaporative equipment. A collection of techniques, rather than rigorous instruction is presented to guide the user. Emphasis is on principles rather than on specific directions. Performance tests may be desired for the following purposes:

101.1.1 Accumulation of data for improving the design or operation of the particular evaporator under observation.

101.1.2 Accumulation of data for designing new equipment in similar service.

101.1.3 Planning of shutdowns for maintenance or cleaning.

101.1.4 Comparison of evaporator performance to that predicted by the manufacturer. (It is not the intent of this procedure to establish permissible deviations of the test performance from the manufacturer's predicted performance. Any such limits should be specified in the purchase specifications.)

101.2 When mutually agreed to by a buyer and a seller, this procedure may be used as a basis for evaluating commercial performance.

102.0 Scope

102.1 This procedure is applicable to all types of indirect steam heated evaporative equipment. Its principal applicability will be to single, multiple effect, and recompression evaporators used for concentration of aqueous solutions by the chemical, food and related industries. It is equally applicable to crystallizing and non-crystallizing types of evaporators.

102.1.1 With proper allowances, this procedure may be applied to evaporation of non-aqueous solutions and to cases where an energy source other than steam is used.

102.1.2 This procedure does not cover the performance testing of equipment auxiliary to the evaporator such as feed and discharge pumps, instruments and control devices, vapor compressors, vacuum sources, feed preheaters and product coolers.

102.2 The performance characteristics covered are:

102.2.1 Evaporative capacity.

102.2.2 Steam economy.

102.3.3 Heat transfer coefficients.

102.2.4 Entrainment and other product losses.

102.2.5 Cleaning cycles.

200.0 DEFINITION AND DESCRIPTION OF TERMS

201.0 Introduction

201.1 The letter symbols in this testing procedure may be used with a subscript, which may designate a place in space or time, a system of units, or a constant or reference value.

201.2 The terminology refers principally to evaporation of aqueous solutions in steam-heated equipment.

201.3 The definitions conform generally to common usage, but as there are many types of evaporators and many kinds of evaporator operation, there are exceptions to some definitions.

202.0 Equipment

202.1 The *evaporator* is the assembly of equipment used for the removal of solvent by evaporation. Flow diagrams in the appendix show typical evaporators.

202.1.1 *Continuous evaporators* are those in which the feed, vapor-removal, and discharge operations are continuous and uniform. In some cases the discharge operation may be accomplished at such short intervals as to provide essentially continuous operation.

202.1.2 *Batch evaporators* are those in which either the feed operation or the discharge operation or both are intermittent.

202.2 The *evaporator body* is the vessel which contains the bulk of the boiling liquor and provides sufficient space for vapor disengagement from the liquor.

202.3 An *effect* is one or more evaporator bodies which have the same operating pressure within the body or bodies.

202.3.1 A *single-effect* evaporator operates at one pressure level in its body or bodies.

202.3.2 A *multiple-effect* evaporator is a series of effects so connected that the vapor from one body or bodies is the heating medium for the next

body or bodies. One effect may consist of a number of bodies operating with the same vapor pressure, with the same or different steam pressure, and with the same or different liquor concentration.

202.3.3 Effects are numbered in the order of decreasing evaporator temperature.

202.4 Area is the surface through which heat transfer takes place, measured on the liquor side of the surface. For tubular surfaces, area is computed on the basis of tube length between outer faces of the tube sheets and does not include the area of the tube sheets.

202.5 *Vapor recompression* is a system in which the vapor leaving an evaporator body is compressed to a pressure where it can be used as heating steam for the same evaporator.

203.0 Feed

203.1 Feed is the liquor to be evaporated.

203.2 Feed flow through a multiple-effect evaporator may be

203.2.1 *Forward Feed*. Feed liquor is fed to the first effect and concentrated liquor is withdrawn from the last effect.

203.2.2 *Backward Feed*. Feed liquor is fed to the last effect and concentrated liquor is withdrawn from the first effect.

203.2.3 *Parallel Feed*. Weak feed liquor is fed to, and concentrated liquor withdrawn from, every effect.

203.2.4 *Mixed Feed*. Mixed feed covers all other systems of feeding and discharging liquor.

203.3 *Liquor* is the fluid undergoing evaporation and may be either a solution or a slurry.

204.0 Steam

204.1 *Steam pressure* is the pressure at which steam condenses in the heating element.

204.2 *Steam quality* is the ratio of pounds of dry steam per pound of wet steam.

204.3 *Steam Economy*

204.3.1 *Net steam economy* is the ratio of pounds of water evaporated from the feed liquor only per pound of steam used.

204.3.2 *Gross steam economy* is the ratio of pounds of water evaporated from all sources per pound of steam used.

205.0 Evaporator Cleaning

205.1 A "clean" evaporator has little or no scale or deposits on its heating surface. A clean surface is normally attainable by ordinary commercial cleaning methods.

205.2 A "fouled" evaporator has sufficient accumu-

lation of scale or other deposits on either the vapor or liquid side of its heating surface to cause a significant drop in its evaporative capacity.

205.3 *Scaling* is the deposition on the heating surface of a solid whose solubility in the heated liquor or in the heating medium decreases with increasing temperature.

205.4 *Salting* is the deposition on the heating surface of a material whose solubility in the heated liquor increases with increasing temperature.

205.5 *Washout* is an evaporator cleaning operation. A washout usually consists of draining the evaporator and refilling it with water or other solutions. In some cases increasing the feed rate provides sufficient washing to clean the evaporator.

205.6 *Boilout* is a washout under boiling conditions.

205.7 *Cleaning cycle* is the length of time from one washout, boilout, or descaling operation to the next.

206.0 General Terms

206.1 *Evaporation* is the concentration of solutions by removal of solvent as vapor. This testing procedure excludes consideration of evaporation in equipment such as dryers or distillation columns.

206.1.1 *Net evaporation* is the amount of solvent removed from the feed liquor only.

206.1.2 *Gross evaporation* is the amount of solvent removed from all sources.

206.2 *Entrainment* is the carry-over of liquid or solids in the vapor leaving the evaporator separator. Normally quantitative definition may be pounds of nonvolatile product lost per pound of vapor removed or percent of nonvolatile component in the feed that is lost with the vapor.

206.3 *Boiling-point rise* (BPR) is the difference between the boiling point of a solution and the boiling point of the solvent at the same pressure.

206.4 *Heat of solution* is the heat evolved or absorbed when a solute dissolves in a solvent.

206.5 *Temperature Difference*

206.5.1 *Temperature difference* is the difference between the steam and the liquor temperatures. It is usually difficult to obtain accurate direct measurements of these temperatures.

206.5.1.1 In the case of all *natural-circulation evaporators*, the temperature difference is arbitrarily defined as the difference between the steam temperature and the boiling-liquor temperature at the pressure existing in the vapor space. (See Section 804.1 for sample calculation.)

206.5.1.2 In the case of *forced-circulation evaporators* when no boiling occurs in the tubes, it is customary to use the log mean temperature difference between the steam temperature and the temperature of the liquor entering and leaving the tubes.

(See Section 804.3 for sample calculation.)

206.5.2 *Apparent temperature difference* is the difference between the steam and liquor temperatures as calculated from pressure measurements in the steam space and the evaporator body, both fluids being assumed pure solvent.

206.5.3 *Corrected temperature difference* is the apparent temperature difference with corrections for boiling-point rise, hydrostatic head, and temperature increase through the heater. Often these corrections are neglected, except for boiling-point rise.

300.0 TEST PLANNING

301.0 Safety

The test procedure should conform to the latest requirements of applicable safety standards. These include but are not limited to plant, industry, Local, State and Federal regulations. The Plant Management and the Evaporator Manufacturer should be requested to furnish in writing specific details, which should become a permanent part of the test record. It is recommended, further, that all testing be conducted by, or under the supervision of, personnel fully experienced in plant and equipment operating procedures.

302.0 Types of Tests

Tests shall be classified as follows:

302.1 *Informational*. Informational tests are those conducted under any given set of conditions to determine performance characteristics. This procedure is directed primarily toward this type of test.

302.2 *Acceptance*. Acceptance tests are those conducted under conditions agreed upon by the vendor and the purchaser for the purpose of determining whether the equipment meets the manufacturer's guarantee.

303.0 Testing

In general, a test should be made only after the following items have been reviewed and their relationship to the test established. The calculation procedures should be examined in order to ensure adequate and proper data.

303.1 Objective

303.1.1 *Primary*. Primary objectives will usually include total evaporative capacity, steam economy, heat transfer rates or coefficients, entrainment or other product losses, and cleaning cycles of heating equipment.

303.1.2 *Secondary*. Secondary objectives might include particle size, heat losses, vent losses, wash-water dilution, contamination by corrosion products, corrosion rates.

303.2 Flow Cycle of System

A sketch showing details of the equipment arrangement to be tested should be prepared. The calculation and interpretation of the data are dependent upon the particular flow cycle and upon the method of control of the evaporator.

303.3 Data Planning

Consideration should be given to obtaining data and performance information on the items below. Cross-check data should be taken wherever possible in order to establish the reliability and consistency of primary data. In many instances it is practical to take informational data on equipment associated with the test, but not the object of primary interest. Such equipment might include vacuum jets, thermocompressors, vacuum pumps, pumps, decanting vessels, centrifuges, etc. Such data may aid in the analysis and understanding of the behavior of the equipment under test. The usual items to consider include:

303.3.1 Chemical and physical analysis should be made of all fluids and/or suspended solid flows that have a bearing on the performance of the equipment. In some instances an expression of concentration in terms of physical properties rather than chemical analysis may be acceptable for the purpose of calculation and interpretation of results. Specific information on other properties peculiar to the system should be determined to characterize the fluids completely. Special attention is directed to the effect of metallic contaminants, defoaming additives, and the like.

303.3.1.1 Feed

303.3.1.2 Product (s)

303.3.1.3 Contents of each evaporator body

303.3.1.4 Intermediate liquid and/or vapor streams

303.3.1.5 Condensate (for product loss)

303.3.1.6 Primary steam

303.3.1.7 Cooling water to and from condenser

303.3.2 The following physical property data may be required. If the chemical identity and necessary pressure and/or temperature conditions are established, the physical data may be taken from accepted tables giving the properties in question over the range of the test conditions.

303.3.2.1 Specific gravity

303.3.2.2 Thermal properties: specific heat, heats of solution, enthalpy, etc.

303.3.2.3 Thermal conductivity

303.3.2.4 Viscosity

303.3.2.5 pH

303.3.2.6 Freezing point

303.3.2.7 Solubility

303.3.2.8 Particle size, structures, and suspended solids content

303.3.2.9 Boiling-point rise

303.3.3 *Measurements*

The measurements needed should be established. Each item of information should be reviewed as to the number and frequency of readings and samples and the accuracy and calibration required for instruments.

Consideration should be given to measuring.

303.3.3.1 Feed, product, steam and condenser-water rate

303.3.3.2 Steam quality

303.3.3.3 Temperatures and pressures:

Locate all points necessary to establish material and heat balances, heat transfer rates, and physical and chemical properties of the fluids in the system. Record the barometric pressure.

303.3.3.4 Pressure drop:

The pressure loss through heating and flashing equipment and system piping should be identified as to acceptable limits if performance can be affected as a result of significant deviation.

303.3.3.5 Cleaning cycle:

Prolonged or repetitive tests may be necessary to obtain sufficient and necessary data.

303.3.3.6 Circulation rate and power consumption.

303.3.3.7 Noncondensables:

These noncondensables are generally estimated indirectly and qualitatively by their effect on performance rather than quantitatively. In-leakage, evolution of dissolved gases, or liberation of gases by chemical reaction may be critical to the performance of the equipment.

303.3.4 *Data Log Sheet*

A log sheet providing space and identification for recording all necessary data in orderly form should be prepared before testing. This sheet should suit the flow cycle, operators, and results to be calculated. (See sample sheet in Section 803.0. It is suggested that the normal plant operating data be included in addition to any special data recorded as part of the test.

303.4 *Physical Facilities*

The physical facilities available, as well as the conditions of the various components of the working test system, should be reviewed and examined.

303.4.1 *Inspection of Entire Setup*

Inspection should be made before testing:

303.4.1.1 Test for tightness of joints, connections, and leaking tubes or evapor-

ator bodies.

303.4.1.2 Ensure that all equipment and connecting piping are free from plugs or obstructions.

303.4.1.3 Inspect for the proper assembly and attachment of all instrument connections.

303.4.1.4 Determine the operability of evaporator and auxiliaries. Dilution water should be accounted for during operation of the system, including points such as pump seals, wash-water connections, tube leakage, and other possible sources. Water connections should be accounted for by metering or definite isolation from the system. Purge-type rotameters should be considered for lantern glands to detect internal water leakage on water-sealed pumps.

303.4.2 Clean all heat-exchange surfaces or place in condition for test.

303.4.3 Locate and provide sample points and devise a method of collecting samples. (See section 408.0.)

303.4.4 Locate and provide data-measuring points.

303.4.5 *Laws and Codes*

Conform to local, state, and federal regulations.

303.5 *Personnel*

Adequate personnel should be available to monitor the test continuously.

304.0 *Acceptance Test Performance*

The following additional factors should be considered when an acceptance test is conducted:

304.1 The contract requirements for test conditions.

304.2 The extrapolation of test data to contract conditions.

304.3 The range of acceptable performance.

304.4 *Heat Transfer Conditions*

304.4.1 It is understood, unless otherwise stated, that performance rates and specifications are to be met under "clean" conditions may need to be established by preliminary tests or agreement. 304.4.2 For batch-type operations, it is understood that performance conditions are to be met over a production time cycle.

400.0 **INSTRUMENTS AND METHODS OF MEASUREMENTS**

A variety of equipment is available, and the choice of instrument will be determined by accuracy required, conditions of test, and personal preference. Where

practical, it is recommended that recording instruments should be calibrated before the test.

Attention is called to precautions that should be taken in measuring. Since knowledge of the properties of the process stream may be required for interpretation of the performance characteristics of the evaporator, methods measuring process-stream properties are also included.

401.0 Fluid-Flow Measurement

401.1 Tanks

Differential volume or differential weight are commonly used as a measure of the flow of fluids from tanks. For test purposes, tanks are recommended for fluid-flow measurements. When fluid-flow measurement is made by use of tanks, it is advisable to make a series of measurements to ensure that steady state conditions are obtained before start of test.

401.1.1 Volumetric Tanks

Suitably designed volumetric tanks can be accurate within $\pm 0.5\%$ of total volume. Volumetric tanks should be calibrated prior to a test with weighted increments of liquid measured at a known temperature. Density corrections should be made for the difference in temperature of the liquid measured and the temperature at the time the tank was calibrated.

401.1.2 Weigh Tanks

The most accurate method of measuring liquids is by weighing. With suitable tanks and scales, accuracies of $\pm 0.2\%$ of full tank weight can be obtained. Weigh tanks should be calibrated over the entire range of loads at which they are to be used.

All liquids being measured in open tanks should be cooled below their boiling point, either by cooling pipes or by being mixed with a known quantity of cold liquid to obtain a final mixture below the boiling point. Conversely, if condensate is being measured, the quality of the steam should be measured if it is not superheated and the quantity of moisture in the steam deducted from the quantity of condensate measured.

References 802.1 and 802.2 give recommendations as to the proper design, construction, calibration, and operation of volumetric and weigh tanks.

402.2 Meters

401.2.1 Differential-Pressure Meters

The rate of flow of fluids is most often measured by differential-pressure flow meters. Types in common use are

401.2.1.1 Orifice meters

401.2.1.2 Venturi meters

401.2.1.3 Flow-nozzle meters: reference 802.1

401.2.1.4 Pitot-tube meters:

References 802.1 and 802.2 give information on design, construction, installation, calibration, and operation of these differential pressure devices.

401.2.2 Rotameters

Rotameters of many types are commercially available and when properly installed, calibrated and kept clean are excellent devices for fluid-flow measurement. See reference 802.9 for information concerning corrections for temperature and pressure.

401.2.3 Weirs

For large flows and flows where $\pm 5\%$ accuracy is satisfactory, weirs may be used for fluid-flow measurement. Accuracy of $\pm 1\%$ may be obtained with a calibrated weir (Reference 802.15)

401.2.4 Positive-Displacement Flow Meters

There are available a variety of fine mechanical meters of the positive-displacement type. Since they are subject to wear and corrosion, they should be checked before use.

401.2.5 Magnetic Flow Meter

A magnetic volumetric-flow meter suitable for liquids that have slight electrical conductivity is available commercially. This meter is reported to be particularly useful for measuring flow of liquids containing suspended solids.

401.2.6 Suggested Precautions

401.2.6.1 It is essential that in cases where it is necessary to purge manometer lines the density of the purge liquid be known and the appropriate correction be made. Unequal or excessive pressure drops in the purge lines should be avoided. It is desirable to use deaerated liquid as a purge fluid in vacuum operation.

401.2.6.2 Leakage dilution which may affect test results, either should be reduced to an amount which may be ignored or should be accounted for in the material balance.

401.2.6.3 Errors due to water entering or leaving equipment under test through connected piping should be obviated by blanking off such piping or providing open tell-tale drains to give visible assurance that no flow exists.

402.0 Temperature Measurement (802.3)

402.1 A variety of temperature measuring, recording, and controlling devices are available. Choice will depend entirely on the specific requirements. The following are some of the types which may be used.

402.1.1 *Indicating Thermometers*

- 402.1.1.1 Mercury in glass
- 402.1.1.2 Bimetallic (frequent calibration required)
- 402.1.1.3 Thermocouple
- 402.1.1.4 Resistance

402.1.2 *Recording Thermometers*

- 402.1.2.1 Mercury
- 402.1.2.2 Gas
- 402.1.2.3 Vapor
- 402.1.2.4 Thermocouple
- 402.1.2.5 Resistance

402.2 Generally evaporator installations will be equipped for operating control with sufficient temperature-measuring devices to provide the necessary measurements for a performance test. Where thermometers must be added, simple devices (e.g., mercury-in-glass thermometers) will suffice provided that they are accurate and properly located and installed.

402.3 *Suggested Precautions*

402.3.1 It is desirable to calibrate all temperature measuring devices before and after each test. Spare calibrated thermometers are often useful during a test.

402.3.2 The location of the thermometer is of the greatest importance. Thermometers should be installed to minimize the error introduced by radiation or convection and should be located in moving and mixed stream to obtain maximum sensitivity and to avoid errors due to stratification of streams.

Possible errors are to measure and report the temperature of the liquor from the heater after flashing has occurred or to report steam temperature as saturated steam when it is actually superheated steam temperature.

402.3.3 Thermometer wells should be as thin as consistent with strength and the internal diameter should be as small as possible. Wells should be clean and free from salting and should extend into the stream being measured.

402.3.4 Instructions regarding immersion of mercury-in-glass thermometers should be followed, and where utmost accuracy is required, a stem temperature correction may be made. If full immersion of mercury-in-glass thermometers is employed, they should be withdrawn as few times as possible and only to the extent required for a reading.

402.3.5 Saturated-steam temperatures may be measured at any point where the steam is not superheated at the pressure for which the temperature measurement is desired. Care should be taken, however, that the thermometer is not cooled by condensate.

403.0 *Pressure Measurement* (802.4)

403.1 Accurate pressure measurement is required for a satisfactory test of evaporator performance. Many types of pressure-measuring devices are available commercially, and generally an evaporator requires for operating control, pressure-measuring instruments suitable for performance testing. Among the type of pressure instruments in common use are

- 403.1.1 Bourdon gauges
- 403.1.2 Bellows-type instruments
- 403.1.3 Differential-pressure cells
- 403.1.4 Mercury manometers
- 403.1.5 Absolute pressure gauges
- 403.1.6 Deadweight gauges

403.2 Bourdon and bellows gauges are accurate to 1/2% of full-scale pressure reading:

- 403.2.1 When used between one quarter and three quarters of full scale.
- 403.2.2 When calibrated within 10°F of temperature of use and not used above 150°F.
- 403.2.3 When calibrated in position of use (i.e., vertical or flat).
- 403.2.4 When calibrated within 48 hours before and after test.

403.3 It is particularly important that pipelines to vacuum gauges be tight to avoid serious errors, especially at high vacuums. A simple test for possible leakage is to provide a valve as near to the point of pressure measurement as possible. If the pipelines are tight, the vacuum reading should not change when this valve is closed.

403.4 Gauge lines filled with vapor should be made self-draining. In cases of gauges with pipes filled with liquid, it may be desirable to have gauges installed at a definite level with respect to apparatus, to simplify correction for liquid in pipes. Proper corrections must be made for any changes in readings resulting from use of purge liquor. The purge liquid should be deaerated if used under vacuum.

403.5 Gauges should be protected from steam with siphons or their equivalent. Convolutions of siphons should be as few as possible consistent with the gauge remaining cool, because of their tendency to introduce errors due to unbalanced water columns in the convolutions.

403.6 Static pressure-measuring connections should be flush with the inner walls.

403.7 Excessive pulsations of pressure shown by a gauge should be adjusted to leave some pulsation. A "column chamber" may be employed (802.4).

404.0 *Boiling-Point Rise*

404.1 Special laboratory apparatus is required to

determine boiling-point rise accurately and to eliminate errors due to superheat and hydrostatic head. (See Reference 802.10 and, for corrosive solutions, reference 802.11). Boiling points of solutions may be approximated by immersing the thermometer directly into the boiling solution.

404.2 Recording and controlling instruments determine the concentration of liquor in the evaporator by measuring the boiling-point rise of the liquid in the evaporator. When such an instrument is used, care should be taken to measure desuperheated vapor temperature.

405.0 Horsepower (802.5)

405.1 In forced-circulation or mechanically agitated evaporators, the operating speed of the pump or agitator can be measured with a tachometer, stroboscope, or speed indicator on the center of the shaft or when the center is inaccessible by a surface speed indicator on the circumference of the shaft.

405.2 The torque of the input shaft may be determined by a strain gauge or other suitable device and the power input calculated from the torque and speed.

405.3 Alternatively the power input to a motor may be obtained by a wattmeter to balance out line variations and provide a continuous record. Actual power input to the evaporator may be calculated, with allowance made for the losses in the motor and the transmission system.

406.0 Entrainment

406.1 A knowledge of entrainment is generally desired as part of an evaporator performance test. While the sampling and sample analysis must be considered as a unique problem for each evaporator installation, the following generalizations may be made (802.18 and 802.19).

406.1.1 Since liquor level affects entrainment, all determinations should be made with notation of level.

406.1.2 The measurement of entrainment can best be determined by analysis or conductivity measurement of condensate, except in the last effect when a surface condenser is not used. Frequent or continuous measurements will be required, since the amount of entrainment may vary greatly.

407.0 Particle-Size Measurement

407.1 Particle-size measurement of particles to $37\ \mu$ may be made with testing sieves. The sample should be either coned and quartered to proper size or reduced in

a splitter. (See reference 802.8 for information concerning measurement of smaller particles.)

407.2 Avoid using a sample of a size that may blind sieve. A test will be required to determine the time required to screen the sample properly.

407.3 Care must be taken in drying sample to avoid agglomeration.

408.0 Sampling

408.1 Liquid

Great care is required to obtain representative slurry samples. The best accuracy can be obtained where a suitable receptacle can cross the flow stream completely for a brief interval. For clear liquids, continuous sampling is desirable.

408.2 Vapor

The collection of a vapor sample presents many special problems and should be used only where absolutely necessary. Usually a specially designed sampling device is required. (See reference 802.12 for description of one such device.)

409.0 Density

409.1 Density may be determined to $\pm .01\%$ accuracy by pycnometer, hydrostatic weighing or by a hydrometer. Specific-gravity determinations should be made at three or more liquid temperatures that span the temperatures of the test conditions.

409.2 Recording and controlling instruments for measuring density are radiation absorption, bubble tube, differential pressure, displacement, and "weight of known volume." Special precautions must be taken to prevent plugging of bubble-tube meters when they are used to measure the density of saturated solutions.

410.0 Viscosity (802.7, 802.13, and 802.14)

Viscosity is used in some cases as a measure of product concentration or quality. Since the various means and units of viscosity measurement are not all mutually convertible with any degree of precision, all measurements should be made with the same type of equipment as originally used in reporting or defining product properties.

500.0 TEST OPERATION

501.0 Preliminary Operation

No comprehensive test of performance should be undertaken until the evaporator has been in normal use long enough for its characteristics to be learned. For test purposes, most or all of the following should be accomplished during preliminary operation:

- 501.1 Train operators
- 501.2 Determine steam rates, feed rates, etc., needed to obtain the desired product and production rate.
- 501.3 Adjust controllers to most stable settings.
- 501.4 Establish best liquid levels, venting rates, etc.
- 501.5 Measure or determine approximate magnitude of heat losses.
- 501.6 Determine lengths of batch cycles and the rate at which conditions change in various parts of the cycles.

502.0 Preliminary Test

After test planning has been completed, a preliminary test should be run to ensure the success of the performance test. This may be a separate test or a preliminary portion of the final test. A complete set of data should be taken during the preliminary test and the results calculated, the calculations being completed before the performance test is started. The purposes of the preliminary test are to

- 502.1 Train test personnel that are not part of the normal operating crew.
- 502.2 Determine whether the test can be run as planned and that the data are adequate in both quantity and quality.
- 502.3 Provide rough data for preliminary calculations to determine whether the calculation procedure is satisfactory.
- 502.4 Determine whether the operating conditions are those desired for the test, such as operation at optimum, design, or performance conditions.
- 502.5 Detect unusual conditions, such as excessive venting or leakage of dilution water into the system.

503.0 Performance Test

In general, the test should be run under normal operating conditions. Special or unusual situations should be recognized. Feed stocks should be selected to establish normal conditions, and adequate quantities should be available for the test duration.

503.1 Duration of Test

503.1.1 Batch evaporator tests should cover at least two complete cycles - more if conditions vary from cycle to cycle. A distinction should be made between tests that cover only the productive part of the cycle and tests that include time and utilities for cleaning operations between productive cycles.

503.1.2 Continuous evaporator tests, as a general rule, should last for 2 to 4 hours after steady state conditions have been established, but longer or shorter tests frequently are more satisfactory.

503.1.2.1 Shorter tests are indicated when:

503.1.2.1.1 Residence time of liquor in the system is so low that the evaporator reacts rapidly to changes in conditions.

503.1.2.1.2 Sealing or salting is so rapid that repetitive short tests yield more information than longer tests.

503.1.2.1.3 The purpose of the test is to determine performance under transient conditions such as at startup.

503.1.2.2 Longer tests are indicated when:

503.1.2.2.1 The evaporator reacts very slowly to changes in conditions

503.1.2.2.2 Tanks available for volumetric measurements are so large that long periods of operation are needed to obtain accurately measurable level changes.

503.1.2.2.3 Control of conditions is so poor that a large number of readings is needed to obtain a more meaningful average. The value of a test under this condition must be questioned.

503.2 Start of Test

503.2.1 All recording instruments should be synchronized before the start of the test.

503.2.2 The collection of data should be started before the test commences to prove that steady state or other desired conditions have been reached. At least two and preferably three complete sets of reading should agree within estimated experimental error before it is concluded that steady state conditions have been reached.

503.2.3 When the test is to be under steady state conditions, liquor flows and concentrations, steam flow, steam pressure, and evaporator vapor pressures should all have become constant or should show a random distribution about an average value. Usually steam pressure, steam flow, or liquor concentrations will be the last to reach steady state, but this will depend on the method of control and type of evaporator.

503.3 Frequency of Readings

503.3.1 Test readings should be taken at intervals of 30 minutes or less.

503.3.2 In tests under steady state conditions, at least three complete sets of readings should be taken during the test period. This includes the collection of samples and the measurement of

flows in batch tanks.

503.3.3 More numerous readings are preferable since it is far easier to eliminate readings from the calculations than it is to repeat the test because not enough readings were taken.

503.3.4 In tests of batch evaporators, results should be calculated from each set of readings or from the averages of groups of readings taken over short time intervals relative to the interval between groups of readings or to the length of the cycle.

503.3.5 Tests of continuous evaporators under salting or scaling conditions can be treated as tests of batch evaporators. The interval between readings may be quite long and the results can be calculated from single readings provided that sufficient sets of results are calculated.

503.3.6 Tests to determine performance of continuous evaporators during start-up or cleaning operations must also be treated in the same manner as tests of batch evaporators.

503.4 Test Records

It is common experience that no set of test records, no matter how full, contain all the information that is later wanted. Every detail of operation, every deviation from established conditions, every unusual occurrence should be fully noted. So far as possible, the original record should also be the permanent record, made in ink at the time of the reading. Test records should include the following:

503.4.1 Flow sheet, showing all pipelines used and all measurement and sampling points.

503.4.2 Data sheet, a typical example of which is shown in Section 803.0, containing all measurements made during the test, together with the identification of all instruments and samples taken.

503.4.3 A written chronological log in which all miscellaneous observations and measurements should be recorded.

503.4.4 All chart records from recording instruments, regardless of whether or not the instrument measurements are to be used in the calculations.

503.4.5 Copies of all laboratory reports on sample analyses.

503.4.6 Copies of all instrument calibrations.

503.4.7 Copies of the normal operator's data taken during the run, in order that the two sets of data may be related to each other.

503.5 Common Causes of Unsatisfactory Tests

It sometimes happens that the measurements taken are accurate and conditions are uniform, but the results are not consistent and nothing in the test records gives a clue to the reason. Frequent causes of such failures,

and ones that usually can be detected only during the test, are as follows:

503.5.1 Failure to remove condensate at the rate it is being formed, thus either blanketing part of the heating surface with condensate or bypassing steam to the next effect.

503.5.2 Venting noncondensables from each heating element at too high or too low a rate. Where size, evaporator condition, or feed properties indicate the possibility of excessive venting, special precautions should be taken to measure flow and/or quality of the vent gas.

503.5.3 Failure to measure steam pressure and temperature at the steam meter.

503.5.4 Failure to measure steam quality when steam meter is calibrated against condensate measurement.

503.5.5 Failure to isolate or measure all possible sources of dilution. The operating procedure should also be observed carefully to detect excessive rinsing of slurry lines, filters, controller connections, and sight glasses.

503.5.6 Operation with scaled, salted or plugged tubes.

503.5.7 Failure to realize that entrainment may be affected seriously by surging, liquid-level variations, air or steam leakage, plugged or salted catch-all drains, contaminants that cause foaming, or by excessive feed temperatures.

503.5.8 Failure to correct inventory or production figures for changes in liquor volume, liquor strength, or slurry concentration in the evaporator.

503.5.9 Failure to note relative elevations of pressure-measurement points on liquid circuits or to record data needed to correct pressure measurements for the effect of purge or sealing fluids.

600.0 COMPUTATION OF RESULTS

601.0 Introduction

601.1 In this section, methods of making the necessary calculations to permit analysis of the operation are outlined, and samples of typical calculations are given in Section 804.0. Only evaporator systems having continuous feed and discharge streams are considered.

601.2 To determine the basic performance characteristics outlined in 102.2, it is generally necessary to prepare a detailed heat and material balance over the evaporator system, calculating the quantities of heat and material entering and leaving each vessel. As a prelude to the preparation of this heat balance, the data to be used must be selected with care, the over-all rate of evaporation determined, and a temperature-level tab-

ulation prepared. (See Section 804.0 for typical calculations covering all these points, including determination of the basic values above.)

601.3 The determination of cleaning cycles is done by the results of a number of tests over a period of time and will be covered in detail in section 700.0.

602.0 Selection of Data

602.1 On completion of the test, the log should be studied carefully, together with the charts from any recording instruments available. Data selected for use in the computations relating to continuous systems should be representative of stable operation extending over at least an hour, at conditions of steam and feed rate, steam pressure, and last effect vapor pressure as close as possible to those originally set for the test, as indicated in Section 500.0. (See typical tabulations of data directly following each flow sheet in Section 804.0 and the suggested log in Section 803.0.)

602.2 Data required for analysis of performance would include the following (some needed only for cross-checking other data):

602.2.1 Feed and product rate, temperature, and concentration.

602.2.2 Steam flow, pressure, and temperature if superheated or quality if wet.

602.2.3 Vapor pressure in all vapor bodies, heating elements, and condenser; barometric pressure.

602.2.4 Temperature of liquor entering and leaving forced-circulation-evaporator heating elements, feed heaters, or intereffect heaters.

602.2.5 Condenser-water flow rate, temperature, and analysis of water entering and leaving the condenser.

602.2.6 Analysis of condensate from all heat-ing elements.

602.2.7 Power consumption of pumps and mechanical compressor drives.

602.2.8 Liquor concentrations in individual evaporator bodies.

602.2.9 Weight of condensate from all heaters and flash tanks, individually or combined, to the extent this is practicable.

602.3 If possible, additional data on the physical characteristics of the liquor being concentrated should be obtained as functions of concentration and temperature including the following:

602.3.1 Boiling-point elevation

602.3.2 Heat of solution

*602.3.3 Enthalpy

602.3.4 Specific heat

*(If this is available, 602.3.2 and 602.3.4 are not required.)

603.0 Determination of Rate of Evaporation

603.1 Net evaporation may be determined in one of the three ways listed below:

603.1.1 By difference between feed and discharge rates.

603.1.2 By measured feed rate and change in concentration.

603.1.3 By measured discharge rate and concentration change.

603.2 Gross evaporation may be determined by direct measurement of all vapor condensate or by measuring water entering the system as pump seal water, wash water, etc., and adding to the net evaporation as determined under 603.1.

604.0 Preparation of Temperature-Distribution Table from Data

604.1 A tabulation is necessary for the preparation of the detailed heat balance, since it establishes the liquor temperatures in each body for use in calculating heating and flashing loads.

604.2 Using the steam- and vapor-pressure measurements from the test data, prepare a table listing the saturated vapor temperatures throughout the evaporator system.

604.3 On the assumption that a correlation of boiling-point rise vs. concentration is available and that the concentrations in the various effects have been determined by test, the boiling-point rise in each effect can be determined and used to calculate the boiling point in each effect for insertion in the temperature-distribution table.

604.4 If the individual concentrations are not known, it will be necessary to assume the concentration in each effect to begin with, substituting the correct concentrations after the first trial heat balance. (See section 804.1.2, for a completed temperature tabulation on a triple-effect evaporator.

605.0 Preparation of Heat and Material Balances

605.1 From the measured steam flow, feed flow, and feed temperature and the temperature-distribution table described under 604.0, prepare a heat and material balance covering each effect of the evaporator. Data will be needed on the specific heat of the solution involved at various concentrations, or assumptions must be made. A completed heat and material balance is shown in detail in section 804.5, which covers a case in which heat of concentration is negligible and boiling-point rise is low.

605.2 Generally, where multiple-effect operation is involved, the simplest way to make a heat and material balance is by trial and error. By inspection, assumptions are made as to evaporation in each effect, thus fixing the feed rate to each effect and the concentra-