# Calculation and Verification of Filling Ratios for Liquified Gases

**DTRS56-02-X-0049**

## Final Report Prepared for:

Mark M. Toughiry, P.E.
Office of Hazardous Materials Technology
Research and Special Programs Administration
U.S. Department of Transportation
Washington, DC 20590-0001

## By:

Dr. Marcia L. Huber
Dr. Daniel G. Friend
Principal Investigators
Physical and Chemical Properties Division
National Institute of Standards and Technology
Boulder, CO 80305-3328

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**Technical Contacts:**

Dr. Daniel G. Friend
303-497-5424 (phone)
303-497-5224 (fax)
Daniel.friend@nist.gov

Dr. Marcia L. Huber
303-497-5252 (phone)
303-497-5224 (fax)
marcia.huber@nist.gov

**Administrative Contact:**

Ms. Beverly Armstrong
303-497-3868 (phone)
303-497-5044 (fax)
beverly.Armstrong@nist.gov

## Introduction

This report describes the work performed and results obtained under Reimbursable Agreement DTRS56-02-X-0049, *Calculation and Verification of Filling Ratios for Liquified Gases*. The major efforts were to establish our best estimates for key properties of select fluids, establish equation of state models to calculate densities at certain conditions, estimate filling ratios for these fluids according to standard protocols, and compare these calculated filling ratios with certain tabulated filling ratios. The fluids studied were those listed in Table 2 of amended Instruction P200 of the UN Model Regulations on the Transport of Dangerous Goods (Committee on the Transport of Dangerous Goods, Report of the Committee of Experts on its Twenty First Session dated 26 January 2001). Filling ratio protocols were developed from the descriptions given in instruction P200 and in DOT 49 CFR, Section 173.304. Comparisons were made with filling ratios (or maximum permitted filling density—percent) tabulated in P200 and in 49 CFR Section 173.304.

The key properties of the fluids are given in Table 1, *Fluid Properties*. The substances are sorted into "high pressure" fluids and "low pressure" fluids, and entries within these two sections are ordered by increasing critical temperature. High pressure fluids are those with critical temperatures between –50 $^{o}$C and 65 $^{o}$C, and low pressure fluids have critical temperatures greater than 65 $^{o}$C, as defined in the P200 document. In Table 1, note that the subscript "c" represents the critical property, so $T_c$ is critical temperature in degrees Celsius, $P_c$ is the critical pressure in megapascals, $\rho_c$ is the critical density in grams per liter (equivalent to grams per cubic decimeter), $V_c$ is the critical volume in liters per kilogram (defined as $1/\rho_c$), and $Z_c$ is the critical compressibility factor (defined by $Z_c = P_c/(\rho_c R T_c)$). Note that the current accepted value of the gas constant[1] is 8.314 472 $J \cdot mol^{-1} \cdot K$; this 1998 CODATA recommended value replaces earlier approximations such as that used in the draft P200 instruction. The sub-heading "ISO" in Table 1 indicates a value taken from the ISO/CD 11622 (Tc-rev1, 2000-09-05) document made available to us by DOT. The values for critical temperature, pressure, and density with the sub-heading "Rec." are our current recommendations; these are consistent with the equation of state reference (EOS ref.) indicated in the final column of the table. The critical volumes and critical compressibility factors were determined from the other table entries as indicated above.

The preferred equation of state sources were the dedicated equations of state that have been thoroughly evaluated and available in NIST standard reference databases[2] 12 or 23; in most of these cases, references to the original literature are given in Table 1. When such an equation of state was not available, calculations were done with the extended corresponding states (EXCST) model used in NIST Standard Reference Database 4; this model has been shown to be generally preferable to cubic equations of state for the calculation of liquid densities. The EXCST model is based on experimental data as available: typically critical properties, vapor pressure curves, and saturated liquid densities are used. For substances not included in Version 3.0 of the NIST Standard

[1] Peter J. Mohr and Barry N. Taylor, *J. Phys. Chem. Reference Data,* Vol. 28, No. 6, pp. 1713-1852, 1999.
[2] Information on NIST Standard Reference Databases are available at http://www.nist.gov/srd/fluids.htm

Reference Database 4, the properties used in the EXCST model were obtained from the American Institute of Chemical Engineers (AIChE) Design Institute for Physical Properties (DIPPR) Project 801 database (Sponsor Version 2.0, DIPPR Diadem, Brigham Young University, 2000). Generally the source data is experimental, but in some cases they are based on evaluated estimation methods. In some cases, experimental data available in the NIST Thermodynamics Research Center Source data system were considered. Note that the molar masses given in Table 1 were chosen to be consistent with the equation of state sources; generally these are based on the 1997 adjustment of the atomic weights of the elements, but for fluids not included in earlier NIST or DIPPR studies, we have used the 1999 IUPAC adjustment[3] for the current project. The differences in the molar masses are generally negligible, and not important for the current study.

The protocols for calculated filling ratios (or maximum permitted filling density—percent) were extracted from the P200 document and 49 CFR Section 173.304. These protocols were established in the first phase of the current project, and the document describing the procedure is included below. Some specific choices, for constants, etc., used in the final calculations are also indicated in this report. Tables 2 and 3 below provide summary comparisons for the "high pressure" fluids and "low pressure" fluids, respectively. Comparisons are provided between the P200 table and current calculations for each test pressure tabulated in P200; comparisons are provided between the CFR 173.304 values and current calculations for fluids and test pressures provided in CFR 173.304. A detailed description of the entries of each column in Table 2 and Table 3 is included below the tables.

More detailed information about each of the calculations can be found in the Excel spreadsheet that accompanies this report. Most of the information in the spreadsheet is self explanatory. Notes attached to some of the cells give information about the source of specific data or estimations, and our estimates of the overall uncertainty in density calculations for each fluid are indicated by the color coding described within the spreadsheet.

[3] T.B. Coplen, Pure Appl. Chem. **73**, No. 4, 667-683, 2001.

# Protocol for DOT Project

(Revised 4/5/02 after discussions with M. Toughiry)

1. Choose 30 fluids from P200 (Table 2).
2. Enter critical temperature from ISO/CD 11622
    a. Verify with IUPAC temperature
    b. Use NIST temperature for work
3. Sort into "high pressure" ( -50 $^{o}$C < $T_c$ < 65 $^{o}$C) and "low pressure" ($T_c$ > 65 $^{o}$C)
4. Calculate filling ratios according to UN Reg.
    a. High Pressure, for each "test pressure," $P_{test}$, in Table 2: Note $P_{test}$ is guage—use 1 bar to convert to absolute.
        i. Check service pressure as 2/3 test pressure—no need to check (as per Mark Toughiry 4/5/02)
        ii. Calculate filling density, $\rho_F$, as $\rho_F = \rho(65\ ^{o}C, P_{test})$ from NIST database
        iii. Calculate filling ratio as $f = \rho_F / \rho_o$; For $\rho_o$, use density of water at 15 $^{o}$C and 0.101 325 MPa (as per MT); may change later
        iv. Compare calculated filling ratio with Table 2
    b. Low Pressure, for each "test pressure," $P_{test}$, (guage pressure) in Table 2
        i. Check that test pressure is greater than or equal to $P_\sigma(65\ ^{o}C) - 0.1$ MPa using NIST database: use absolute P for each and then don't subtract 0.1 MPa.
        **ii.** Calculate test density as $\rho_{test} = \rho(50\ ^{o}C, P_{test})$ from NIST database;
        iii. Calculate filling density as $\rho_F = 0.95\ \rho_{test}$
        iv. Compare $\rho_F$ with $\rho_\sigma(60\ ^{o}C)$ from NIST database; ensure that $\rho_F < \rho_\sigma(60\ ^{o}C)$
        v. Calculate filling ratio as $f = \rho_F / \rho_o$ (Use $\rho_o$ from above.)
        vi. Compare calculated filling ratio with Table 2
    c. Check for any notes in P200 relevant to fluids selected.
5. Calculate filling ratios according to 49 CFR 173.304 (a) (2)
    **a.** For each test pressure in P200, determine a nominal service pressure by multiplying by 3/5 (must use absolute test pressure).
    **b.** Convert nominal service pressure to psig.
    **c.** Choose service pressure from 49 CFR 173.304 (a) (2) list—final digits in container code is psig; choose closest to result from 5b.
    **d.** Determine test pressure using $P_{test} = 5/3\ P_s$ (use absolute)
    e. Calculate filling density, $\rho_F$, as $\rho_F = \rho(130\ ^{o}F, P_{test})$ from NIST database
    f. Compare $\rho_F$ with $\rho_\sigma(130\ ^{o}F)$ from NIST database; ensure that $\rho_F < \rho_\sigma(130\ ^{o}F)$

g. Calculate filling ratio as $f = \rho_F / \rho_o$; Use density of water at 60 $^oF$ equal to 27.737 $in^3/lb$ (as per MT; may change later)

**h.** Compare calculated filling ratio with 49 CFR 173.304 (a) (2).

i. Use test pressure of 3000 psig; calculate filling density, $\rho_F$, as $\rho_F = \rho(130\ ^oF, 3000\ psig)$ from NIST database

**j.** Calculate filling ratio as $f = \rho_F / \rho_o$; use $\rho_o$ from above.

**k.** Compare calculated filling ratio with 49 CFR 173.304 (a) (2).

**l.** Check for any notes in 49 CFR 173.301 to 304 relevant to fluids selected.

**6.** Compile critical temperatures, pressures, compressibility factors, and references for each fluid.

7. Prepare written report summarizing findings. Primary result will be table comparing 5 filling ratios: UN, 49 CFR 173.304 (a) (2), our calculation using UN method, our calculation using 49 CFR 173.304 (a) (2) method, and our calculation using 3000 psig. (MT will send copies of ANSI 239.18 and SF 298 for possible final format; but this is not important.)

## Table 1. Fluid Properties

| UN # | Fluid | $T_c$(°C ) ISO | $T_c$ (°C) Rec. | $P_c$(MPa) Rec. | $\rho_c$(g/l) Rec. | $V_c$(l/kg) Rec. | Molar mass | $Z_c$ | EOS ref. |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | Tetrafluoromethane (R14) | -45.7 | -45.64 | 3.75 | 625.66 | 1.598 | 88.005 | 0.279 | [1] |
| 2451 | Nitrogen Trifluoride | -39.3 | -39.15 | 4.46 | 562.47 | 1.778 | 71.019 | 0.289 | [2] |
| 1859 | Silicon tetrafluoride | -14.2 | -14.15 | 3.72 | 515.46 | 1.940 | 104.079 | 0.349 | [3] |
| 1008 | boron trifluoride, BF3 | -12.2 | -12.25 | 4.99 | 549.44 | 1.820 | 67.806 | 0.284 | [4] |
| 2203 | Silane | -3.5 | -3.45 | 4.84 | 242.13 | 4.130 | 32.117 | 0.286 | [5] |
| 1962 | Ethylene | 9.2 | 9.2 | 5.04 | 214.25 | 4.667 | 28.054 | 0.281 | [6] |
| 2417 | carbonyl fluoride | 14.7 | 23.85 | 5.76 | 467.29 | 2.140 | 66.007 | 0.329 | [7] |
| 1911 | Diborane | 16 | 16.65 | 4.05 | 159.74 | 6.260 | 27.67 | 0.291 | [8] |
| 2036 | Xenon | 16.6 | 16.584 | 5.84 | 1099 | 0.910 | 131.3 | 0.290 | [9] |
| 2599 | R503 | na | 18.595 | 4.30 | 552.93 | 1.809 | 87.247 | 0.280 | [10] |
| 2198 | phosphorous pentafluoride | 19 | 18.95 | 3.39 | 623.59 | 1.604 | 125.966 | 0.282 | [11] |
| 2193 | Hexafluoroethane (R116) | 19.7 | 19.88 | 3.04 | 622 | 1.608 | 138.01 | 0.277 | [12] |
| 1984 | Trifluoromethane (R23) | 26 | 26.143 | 4.83 | 526.5 | 1.899 | 70.014 | 0.258 | [13] |
| 1022 | Chlorotrifluoromethane (R13) | 28.8 | 28.85 | 3.88 | 582.88 | 1.716 | 104.46 | 0.277 | [14] |
| 1959 | 1,1-difluoroethylene | 29.7 | 29.65 | 4.46 | 416.67 | 2.400 | 64.035 | 0.273 | [15] |
| 1013 | Carbon Dioxide | 30.1 | 30.978 | 7.38 | 467.6 | 2.139 | 44.01 | 0.275 | [16] |
| 1035 | Ethane | 32.3 | 32.18 | 4.87 | 206.58 | 4.841 | 30.07 | 0.279 | [17] |
| 1081 | Tetrafluoroethylene | 33.3 | 33.3 | 3.94 | 581.4 | 1.720 | 100.016 | 0.266 | [18] |
| 2192 | Germane | 34.8 | 34.85 | 5.55 | 546.45 | 1.830 | 76.642 | 0.303 | [19] |
| 1001 | Acetylene | na | 35.15 | 6.14 | 232.5 | 4.301 | 26.038 | 0.268 | [20] |
| 1070 | Nitrous oxide | 36.4 | 36.42 | 7.25 | 452.49 | 2.210 | 44.013 | 0.274 | [21] |
| 1080 | Sulphur Hexafluoride | 45.6 | 45.583 | 3.75 | 743.81 | 1.344 | 146.06 | 0.278 | [22] |
| 2454 | Methyl Fluoride (R41) | na | 44.13 | 5.90 | 316.51 | 3.159 | 34.033 | 0.240 | [23] |
| 1050 | Hydrogen chloride | 51.5 | 51.5 | 8.31 | 450.45 | 2.220 | 36.461 | 0.249 | [24] |
| 2199 | Phosphine | 51.9 | 51.6 | 6.54 | 301.2 | 3.320 | 33.998 | 0.274 | [25] |
| 1860 | vinyl fluoride | 54.7 | 54.65 | 5.24 | 319.49 | 3.130 | 46.044 | 0.277 | [26] |
| 3220 | Pentafluoroethane (R125) | 66.3 | 66.015 | 3.63 | 568 | 1.761 | 120.02 | 0.272 | [27] |
| 1009 | Bromotrifluoromethane (R13B1) | 66.8 | 67 | 3.97 | 746.27 | 1.340 | 148.91 | 0.281 | [28] |
| 2424 | Octafluoropropane (R218) | 71.9 | 71.95 | 2.67 | 627.98 | 1.592 | 188.02 | 0.279 | [29] |
| 3337 | R404A | na | 71.977 | 3.72 | 487.85 | 2.050 | 97.604 | 0.260 | [30] |
| 2035 | 1,1,1-trifluoroethane (R143a) | 73.1 | 72.707 | 3.76 | 431 | 2.320 | 84.041 | 0.255 | [31] |

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|---|---|---|---|---|---|---|---|---|---|
| 3339 | R407B | na | 74.284 | 4.07 | 563.43 | 1.775 | 102.94 | 0.257 | [32] |
| 3252 | Difluoromethane (R32) | 78 | 78.105 | 5.78 | 424 | 2.358 | 52.024 | 0.243 | [33] |
| 1020 | Chloropentafluoroethane (R115) | 80 | 79.95 | 3.12 | 613.1 | 1.631 | 154.47 | 0.268 | [34] |
| 1973 | R502 | na | 80.727 | 3.97 | 568.92 | 1.758 | 111.63 | 0.264 | [35] |
| 3338 | R407A | na | 81.864 | 4.48 | 531.97 | 1.880 | 90.111 | 0.257 | [36] |
| 2195 | telurium hexafluoride | 83.2 | 107.03 | 3.45 | 961.6 | 1.040 | 241.59 | 0.274 | [37] |
| 2420 | Hexafluoroacetone | 84.1 | 83.99 | 2.84 | 505.05 | 1.980 | 166.023 | 0.314 | [38] |
| 3340 | R407C | na | 86.021 | 4.63 | 513.21 | 1.949 | 86.204 | 0.261 | [39] |
| 1858 | Hexafluoropropylene | 86.2 | 94.85 | 2.90 | 558.66 | 1.790 | 150.023 | 0.254 | [40] |
| 3153 | perfluoromethylvinylether | 87 | 89.85 | 3.11 | 574.71 | 1.740 | 166.023 | 0.298 | [41] |
| 1048 | Hydrogen bromide | 89.9 | 90.0 | 8.55 | 806.45 | 1.240 | 80.912 | 0.283 | [42] |
| 2191 | sulphuryl fluoride | 91 | 67.85 | 7.50 | 515.45 | 1.940 | 102.06 | 0.524 | [43] |
| 2418 | sulphur tetrafluoride | 91 | 90.95 | 4.60 | 600.33 | 1.666 | 108.0596 | 0.274 | [44] |
| 1077 | Propylene | 92.4 | 92.42 | 4.66 | 223.39 | 4.476 | 42.08 | 0.289 | [45] |
| 3083 | Perchloryl fluoride | 95.2 | 95.25 | 5.37 | 636.94 | 1.570 | 102.449 | 0.282 | [46] |
| 2194 | selenium hexafluoride | na | 95.65 | 4.48 | 1027.8 | 0.973 | 192.95 | 0.274 | [47] |
| 1018 | Chlorodifluoromethane (R22) | 96.2 | 96.145 | 4.99 | 523.84 | 1.909 | 86.468 | 0.268 | [48] |
| 1978 | Propane | 96.8 | 96.675 | 4.25 | 218.5 | 4.577 | 44.096 | 0.279 | [49] |
| 2422 | octafluorobut-2-ene | 98.3 | 118.85 | 2.33 | 578.03 | 1.730 | 200.031 | 0.248 | [50] |
| 2188 | Arsine | 99.9 | 99.85 | 6.55 | 800 | 1.250 | 77.945 | 0.207 | [51] |
| 1053 | Hydrogen sulphide | 100 | 100.45 | 9.01 | 347.06 | 2.881 | 34.082 | 0.285 | [52] |
| 3296 | heptafluoropropane (R227ea) | 100 | 101.65 | 2.93 | 573 | 1.745 | 170.03 | 0.279 | [53] |
| 3159 | 1,1,1,2-tetrafluoroethane (R134a) | 101.1 | 101.06 | 4.06 | 511.9 | 1.954 | 102.03 | 0.260 | [54] |
| 2204 | carbonyl sulphide | 102 | 105.65 | 6.35 | 444.44 | 2.250 | 60.076 | 0.272 | [55] |
| 2602 | R500 | na | 102.15 | 4.17 | 491.98 | 2.033 | 99.303 | 0.270 | [56] |
| 2453 | Ethyl fluoride (R161) | 102.2 | 102.16 | 5.03 | 293.26 | 3.410 | 48.06 | 0.264 | [57] |
| 1082 | Trifluorochloroethylene | 105.8 | 106.0 | 4.05 | 549.45 | 1.820 | 116.47 | 0.273 | [58] |
| 3057 | Trifluoroacetylchloride | 109 | 112.85 | 4.40 | 538.49 | 1.857 | 132.4696 | 0.337 | [59] |
| 1028 | Dichlorodifluoromethane (R12) | 112 | 111.97 | 4.14 | 565 | 1.770 | 120.91 | 0.276 | [60] |
| 1030 | 1,1-difluoroethane (R152a) | 113.5 | 113.26 | 4.52 | 368 | 2.717 | 66.051 | 0.252 | [61] |
| 1976 | Octafluorocyclobutane (RC318) | 115.3 | 115.23 | 2.78 | 619.97 | 1.613 | 200.03 | 0.278 | [62] |
| 2200 | Propadiene | 120.7 | 120.85 | 5.25 | 242.72 | 4.120 | 40.065 | 0.264 | [63] |
| 1021 | 1-chloro-1,2,2,2-tetrafluoroethane (R124) | na | 122.28 | 3.62 | 560 | 1.786 | 136.48 | 0.269 | [64] |
| 1027 | Cyclopropane | 125.2 | 125.15 | 5.58 | 258.5 | 3.868 | 42.081 | 0.274 | [65] |

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|---|---|---|---|---|---|---|---|---|---|
| 1033 | dimethyl ether | 126.9 | 126.95 | 5.37 | 271 | 3.690 | 46.069 | 0.274 | [66] |
| 1026 | Cyanogen | 126.6 | 127.0 | 5.98 | 266.67 | 3.750 | 52.036 | 0.351 | [67] |
| 1005 | Ammonia, Anhydrous | 132.4 | 132.25 | 11.33 | 225 | 4.444 | 17.03 | 0.254 | [68] |
| 3154 | perfluoroethylvinylether | 132.8 | 127.85 | 2.80 | 602.41 | 1.660 | 216.031 | 0.301 | [69] |
| 1969 | Isobutane | 134.9 | 134.67 | 3.64 | 224.35 | 4.457 | 58.122 | 0.278 | [70] |
| 2517 | 1-chloro-1,1-difluoroethane (R142b) | 137.1 | 137.11 | 4.07 | 446 | 2.242 | 100.5 | 0.269 | [71] |
| 2202 | Hydrogen selenide | 138 | 138.0 | 8.92 | 675.68 | 1.480 | 80.976 | 0.313 | [72] |
| 2548 | chlorine pentafluoride | 142.6 | 142.85 | 5.26 | 564.92 | 1.770 | 130.44 | 0.351 | [73] |
| 1063 | Methyl chloride | 143 | 143.1 | 6.68 | 353.36 | 2.830 | 50.488 | 0.276 | [74] |
| 1017 | Chlorine | 144 | 144.0 | 7.71 | 571.43 | 1.750 | 70.905 | 0.276 | [75] |
| 1055 | Isobutylene (2-methylpropene) | 144.7 | 144.75 | 4.00 | 234.74 | 4.260 | 56.108 | 0.275 | [76] |
| 1958 | 1,2-dichloro-1,1,2,2-tetrafluoroethane (R114) | 145.7 | 145.68 | 3.26 | 579.97 | 1.724 | 170.92 | 0.276 | [77] |
| 1012 | 1-butylene | 146.4 | 146.35 | 4.02 | 232.56 | 4.300 | 56.108 | 0.241 | [78] |
| 1983 | 1-chloro-2,2,2-trifluoroethane (R133a) | 150 | 156.85 | 3.84 | 497.51 | 2.010 | 118.486 | 0.256 | [79] |
| 2197 | Hydrogen iodide | 150.8 | 150.7 | 8.31 | 1052.63 | 0.950 | 127.912 | 0.287 | [80] |
| 1011 | Butane | 152 | 151.98 | 3.80 | 227.84 | 4.389 | 58.122 | 0.274 | [81] |
| 1010 | 1,3-butadiene | 152 | 151.85 | 4.32 | 244.5 | 4.090 | 54.092 | 0.270 | [82] |
| 1749 | chlorine trifluoride | 153.7 | 182.85 | 5.00 | 674.81 | 1.482 | 92.4484 | 0.181 | [83] |
| 1974 | Chlorodifluorobromomethane (R12B1) | 153.7 | 153.0 | 4.25 | 671.14 | 1.490 | 165.365 | 0.295 | [84] |
| 1012 | Trans-2-butylene | 155.5 | 155.45 | 4.10 | 235.85 | 4.240 | 56.108 | 0.274 | [85] |
| 1086 | Vinyl chloride | 156.5 | 158.85 | 5.67 | 349.65 | 2.860 | 62.499 | 0.283 | [86] |
| 1061 | Methylamine | 156.9 | 156.9 | 7.46 | 201.61 | 4.960 | 31.057 | 0.321 | [87] |
| 1079 | Sulphur Dioxide | 157.5 | 157.49 | 7.88 | 525.01 | 1.905 | 64.065 | 0.269 | [88] |
| 1067 | nitrogen dioxide | 158 | 158.0 | 10.13 | 558.66 | 1.790 | 46.006 | 0.233 | [89] |
| 1083 | Trimethylamine | 160.2 | 160.1 | 4.07 | 232.72 | 4.297 | 59.111 | 0.287 | [90] |
| 2044 | 2,2-dimethylpropane (neopentane) | 160.6 | 160.65 | 3.20 | 234.74 | 4.260 | 72.15 | 0.272 | [91] |
| 1012 | cis-2-butylene | 162.4 | 162.35 | 4.21 | 239.81 | 4.170 | 56.108 | 0.272 | [92] |
| 1032 | Dimethylamine | 164.6 | 164.05 | 5.34 | 250.63 | 3.990 | 45.084 | 0.264 | [93] |
| 1039 | Ethyl methyl ether | 164.7 | 164.65 | 4.40 | 271.74 | 3.680 | 60.096 | 0.267 | [94] |
| 1069 | nitrosyl chloride | 167.5 | 167.5 | 9.12 | 471.7 | 2.120 | 65.459 | 0.346 | [95] |
| 2196 | tungsten hexafluoride | 170 | 179.55 | 4.57 | 2978.4 | 0.336 | 297.84 | 0.121 | [96] |
| 1087 | Vinyl methyl ether | 171.6 | 163.85 | 4.67 | 276.24 | 3.620 | 58.08 | 0.270 | [97] |
| 2676 | Stibine | 173 | 167.2 | 7.31 | 793.7 | 1.260 | 124.77 | 0.314 | [98] |
| 1010 | 1,2-butadiene | 176.1 | 178.85 | 4.36 | 245.7 | 4.070 | 54.092 | 0.255 | [99] |

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|---|---|---|---|---|---|---|---|---|---|
| 1029 | dichlorofluoromethane (R21) | 178.5 | 178.43 | 5.18 | 526.33 | 1.900 | 102.923 | 0.271 | [100] |
| 1741 | boron trichloride | 178.8 | 178.8 | 3.87 | 787.4 | 1.270 | 117.169 | 0.153 | [101] |
| 1076 | Phosgene | 182.3 | 181.85 | 5.67 | 520.83 | 1.920 | 98.916 | 0.285 | [102] |
| 1036 | Ethylamine | 183.4 | 183.0 | 5.62 | 217.86 | 4.590 | 45.084 | 0.307 | [103] |
| 1051 | Hydrogen cyanide | 183.5 | 183.5 | 5.39 | 194.55 | 5.140 | 27.026 | 0.197 | [104] |
| 2419 | bromotrifluoroethylene | 184.8 | 158.85 | 4.48 | 671.14 | 1.490 | 160.921 | 0.298 | [105] |
| 2189 | Dichlorosilane | 176.3 | 185.85 | 4.59 | 425.53 | 2.350 | 101.007 | 0.285 | [106] |
| 2601 | Cyclobutane | 186.8 | 186.78 | 4.98 | 267.38 | 3.740 | 56.108 | 0.273 | [107] |
| 1037 | Ethyl chloride | 187.2 | 187.2 | 5.27 | 322.58 | 3.100 | 64.514 | 0.275 | [108] |
| 1052 | Hydrogen fluoride | na | 188.0 | 6.48 | 289.86 | 3.450 | 20.006 | 0.117 | [109] |
| 2452 | Ethylacetylene | 190.5 | 166.85 | 4.60 | 259.74 | 3.850 | 54.092 | 0.262 | [110] |
| 1062 | Methyl bromide | 194 | 193.85 | 8.00 | 609.76 | 1.640 | 94.939 | 0.321 | [111] |
| 1040 | ethylene oxide | 195.8 | 196.0 | 7.19 | 314.47 | 3.180 | 44.053 | 0.259 | [112] |
| 1064 | Methyl mercaptan | 196.8 | 196.8 | 7.23 | 332.23 | 3.010 | 48.109 | 0.268 | [113] |
| 1085 | Vinyl bromide | 198 | 199.85 | 7.18 | 534.76 | 1.870 | 106.95 | 0.365 | [114] |
| 1589 | Cyanogens chloride | 215 | 175.85 | 5.99 | 377.36 | 2.650 | 61.47 | 0.262 | [115] |
| 1745 | bromine pentafluoride | na | 213.85 | 4.20 | 780.8 | 1.281 | 174.9 | 0.232 | [116] |
| 2495 | iodine pentafluoride | na | 305.85 | 3.70 | 887.6 | 1.127 | 221.9 | 0.192 | [117] |
| 1746 | bromine trifluoride | na | 362.85 | 5.30 | 805.29 | 1.242 | 136.9 | 0.1704 | [118] |
| 2901 | bromine chloride | na | Na | Na | na | na | 115.36 | na | [119] |

**Table 2. "High Pressure" fluids (-50˚C <Tc <65˚C)**

| UN Number | Name | $T_c$ (°C) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 °F, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | Tetrafluoromethane (R14) | -45.64 | 200 | 0.62 | 0.71 | 0.77 | | | |
| 1982 | Tetrafluoromethane (R14) | -45.64 | 300 | 0.94 | 0.90 | 0.77 | | | |
| 2451 | Nitrogen Trifluoride | -39.15 | 200 | 0.50 | 0.63 | 0.69 | | | |
| 2451 | Nitrogen Trifluoride | -39.15 | 300 | 0.75 | 0.82 | 0.69 | | | |
| 1859 | silicon tetrafluoride | -14.15 | 200 | 0.74 | 0.96 | 1.04 | | | |
| 1859 | silicon tetrafluoride | -14.15 | 300 | 1.10 | 1.17 | 1.04 | | | |
| 1008 | Boron trifluoride, BF3 | -12.25 | 225 | 0.72 | 0.76 | 0.78 | | | |
| 1008 | Boron trifluoride, BF3 | -12.25 | 300 | 0.86 | 0.89 | 0.78 | | | |
| 2203 | Silane | -3.45 | 225 | 0.32 | 0.33 | 0.34 | | | |
| 2203 | Silane | -3.45 | 250 | 0.36 | 0.35 | 0.34 | | | |
| 1962 | Ethylene | 9.2 | 225 | 0.34 | 0.34 | 0.35 | 208.5 | 0.35 | 0.31 |
| 1962 | Ethylene | 9.2 | 300 | 0.37 | 0.38 | 0.35 | 277.5 | 0.39 | 0.36 |
| 2417 | carbonyl fluoride | 23.85 | 200 | 0.47 | 0.72 | 0.77 | | | |
| 2417 | carbonyl fluoride | 23.85 | 300 | 0.70 | 0.83 | 0.77 | | | |
| 1911 | Diborane | 16.65 | 250 | 0.07 | 0.30 | 0.29 | | | |
| 2036 | Xenon | 16.584 | 130 | 1.24 | 1.28 | 1.86 | | | |
| 2599 | R503 | 18.595 | 31 | 0.11 | 0.12 | 1.02 | | | |
| 2599 | R503 | 18.595 | 42 | 0.20 | 0.17 | 1.02 | | | |
| 2599 | R503 | 18.595 | 100 | 0.66 | 0.64 | 1.02 | | | |
| 2198 | phosphorous pentafluoride | 18.95 | 200 | 0.90 | 1.12 | 1.18 | | | |
| 2198 | phosphorous pentafluoride | 18.95 | 300 | 1.34 | 1.25 | 1.18 | | | |
| 2193 | Hexafluoroethane (R116) | 19.88 | 200 | 1.10 | 1.13 | 1.19 | | | |
| 1984 | Trifluoromethane (R23) | 26.143 | 190 | 0.87 | 0.88 | 0.96 | | | |
| 1984 | Trifluoromethane (R23) | 26.143 | 250 | 0.95 | 0.96 | 0.96 | | | |
| 1022 | Chlorotrifluoromethane(R13) | 28.85 | 100 | 0.83 | 0.82 | 1.10 | | | |
| 1022 | Chlorotrifluoromethane(R13) | 28.85 | 120 | 0.90 | 0.90 | 1.10 | | | |
| 1022 | Chlorotrifluoromethane(R13) | 28.85 | 190 | 1.04 | 1.04 | 1.10 | 208.5 | 1.11 | 1.00 |
| 1022 | Chlorotrifluoromethane(R13) | 28.85 | 250 | 1.10 | 1.11 | 1.10 | | | |

**Table 2. "High Pressure" fluids (-50˚C <Tc <65˚C), continued.**

| UN Number | Name | $T_c$ (°C) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 °F, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 1959 | 1,1-difluoroethylene | 29.65 | 250 | 0.77 | 0.77 | 0.77 | 254.5 | 0.80 | 0.73 |
| 1013 | Carbon Dioxide | 30.978 | 190 | 0.66 | 0.68 | 0.77 | 208.5 | 0.77 | 0.68 |
| 1013 | Carbon Dioxide | 30.978 | 250 | 0.75 | 0.76 | 0.77 | 231.5 | 0.80 | 0.68 |
| 1035 | Ethane | 32.18 | 95 | 0.25 | 0.25 | 0.38 | | | |
| 1035 | Ethane | 32.18 | 120 | 0.29 | 0.30 | 0.38 | 208.5 | 0.38 | 0.36 |
| 1035 | Ethane | 32.18 | 300 | 0.39 | 0.40 | 0.38 | 231.5 | 0.39 | 0.37 |
| 1081 | Tetrafluoroethylene | 33.3 | 200 | Na | 1.04 | 1.10 | 208.5 | 1.10 | 0.90 |
| 2192 | Germane | 34.85 | 250 | 1.02 | 1.00 | 1.00 | | | |
| 1001 | Acetylene | 35.15 | 60 | na | 0.08 | 0.41 | | | |
| 1001 | Acetylene | 35.15 | 52 | na | 0.07 | 0.41 | | | |
| 3374 | Acetylene | 35.15 | 52 | na | 0.07 | 0.41 | | | |
| 3374 | Acetylene | 35.15 | 60 | na | 0.08 | 0.41 | | | |
| 1070 | nitrous oxide | 36.42 | 180 | 0.68 | 0.66 | 0.76 | | | |
| 1070 | nitrous oxide | 36.42 | 225 | 0.74 | 0.73 | 0.76 | 208.5 | 0.77 | 0.68 |
| 1070 | nitrous oxide | 36.42 | 250 | 0.75 | 0.76 | 0.76 | | | |
| 1080 | SulphurHexafluoride | 45.583 | 70 | 1.04 | 1.06 | 1.49 | | | |
| 1080 | SulphurHexafluoride | 45.583 | 140 | 1.33 | 1.34 | 1.49 | 116.6 | 1.36 | 1.20 |
| 1080 | SulphurHexafluoride | 45.583 | 160 | 1.37 | 1.38 | 1.49 | | | |
| 2454 | MethylFluoride(R41) | 44.13 | 300 | 0.36 | 0.63 | 0.61 | | | |
| 1050 | Hydrogen chloride | 51.5 | 100 | 0.30 | 0.38 | 0.78 | | | |
| 1050 | Hydrogen chloride | 51.5 | 120 | 0.56 | 0.59 | 0.78 | | | |
| 1050 | Hydrogen chloride | 51.5 | 150 | 0.67 | 0.66 | 0.78 | | | |
| 1050 | Hydrogen chloride | 51.5 | 200 | 0.74 | 0.72 | 0.78 | 208.5 | 0.78 | 0.65 |
| 2199 | Phosphine | 51.6 | 225 | 0.30 | 0.50 | 0.52 | | | |
| 2199 | Phosphine | 51.6 | 250 | 0.45 | 0.51 | 0.52 | | | |
| 1860 | vinyl fluoride | 54.65 | 250 | 0.64 | 0.65 | 0.65 | 208.5 | 0.65 | 0.62 |

**Table 3. "Low Pressure" Fluids (Tc > 65˚C)**

| UN Number | Name | $T_c$ (°C) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 °F, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 3220 | Pentafluoroethane (R125) | 66.015 | 49 | 0.95 | 0.87 | 1.25 | | | |
| 3220 | Pentafluoroethane (R125) | 66.015 | 36 | 0.72 | 0.87 | 1.25 | | | |
| 1009 | Bromotrifluoromethane (R13B1) | 67 | 42 | 1.13 | 1.15 | 1.62 | 47.7 | 1.24 | 1.24 |
| 1009 | Bromotrifluoromethane | 67 | 120 | 1.44 | 1.15 | 1.62 | | | |
| 1009 | Bromotrifluoromethane | 67 | 250 | 1.60 | 1.15 | 1.62 | | | |
| 2424 | Octafluoropropane (R218) | 71.95 | 25 | 1.09 | 1.04 | 1.41 | | | |
| 3337 | R404A | 71.977 | 36 | 0.82 | 0.81 | 1.09 | | | |
| 2035 | 1,1,1-trifluoroethane (R143a) | 72.707 | 35 | 0.75 | 0.73 | 0.97 | | | |
| 3339 | R407B | 74.284 | 38 | 0.93 | 0.93 | 1.20 | | | |
| 3252 | Difluoromethane (R32) | 78.105 | 48 | 0.78 | 0.77 | 0.96 | | | |
| 1020 | Chloropentafluoroethane (R115) | 79.95 | 25 | 1.08 | 1.05 | 1.35 | 27.5 | 1.10 | 1.10 |
| 1973 | R502 | 80.727 | 31 | 1.05 | 1.01 | 1.25 | | | |
| 3338 | R407A | 81.864 | 36 | 0.94 | 0.94 | 1.16 | | | |
| 2195 | telurium hexafluoride | 107.03 | 20 | 1.00 | 2.37 | 2.71 | | | |
| 2420 | hexafluoroacetone | 83.99 | 22 | 1.08 | 1.11 | 1.38 | | | |
| 3340 | R407C | 86.021 | 35 | 0.95 | 0.95 | 1.15 | | | |
| 1858 | hexafluoropropylene | 94.85 | 22 | 1.11 | 1.11 | 1.33 | | | |
| 3153 | perfluoromethylvinylether | 89.85 | 20 | 0.75 | 1.02 | 1.29 | | | |
| 1048 | Hydrogen bromide | 90 | 60 | 1.54 | 1.48 | 1.71 | | | |
| 2191 | Sulphuryl fluoride | 67.85 | 50 | 1.10 | 1.09 | 1.40 | 56.8 | 1.14 | 1.06 |
| 2418 | sulphur tetrafluoride | 90.95 | 30 | 0.91 | 1.37 | 1.55 | | | |
| 1077 | Propylene | 92.42 | 30 | 0.43 | 0.43 | 0.52 | | | |
| 3083 | Perchloryl fluoride | 95.25 | 33 | 1.21 | 1.21 | 1.41 | | | |
| 2194 | selenium hexafluoride | 95.65 | 36 | 1.46 | 1.74 | 2.09 | | | |
| 1018 | Chlorodifluoromethane (R22) | 96.145 | 29 | 1.03 | 1.03 | 1.19 | 29.3 | 1.06 | 1.05 |
| 1978 | Propane | 96.675 | 25 | 0.42 | 0.43 | 0.50 | | | |
| 2422 | octafluorobut-2-ene | 118.85 | 12 | 1.34 | 1.31 | 1.51 | | | |

**Table 3. "Low Pressure" Fluids (Tc > 65˚C), continued.**

| UN Number | Name | $T_c$ (°C) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 °F, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 2188 | Arsine | 99.85 | 42 | 1.10 | 1.16 | 1.32 | | | |
| 1053 | hydrogen sulphide | 100.45 | 55 | 0.67 | 0.67 | 0.76 | 56.8 | 0.69 | 0.63 |
| 3296 | heptafluoropropane (R227ea) | 101.65 | 15 | 1.20 | 1.22 | 1.42 | | | |
| 3159 | 1,1,11,2-tetrafluoroethane (R134a) | 101.06 | 22 | 1.04 | 1.05 | 1.21 | | | |
| 2204 | carbonyl sulphide | 105.65 | 26 | 0.84 | 0.89 | 1.00 | | | |
| 2602 | R500 | 102.15 | 22 | 1.01 | 1.00 | 1.16 | | | |
| 2453 | ethyl fluoride | 102.16 | 30 | 0.57 | 0.63 | 0.71 | | | |
| 1082 | Trifluorochloroethylene | 106 | 19 | 1.13 | 1.12 | 1.28 | 36.2 | 1.15 | 1.15 |
| 3057 | Trifluoroacetylchloride | 112.85 | 17 | 1.17 | 1.21 | 1.38 | | | |
| 1028 | Dichlorodifluoromethane (R12) | 111.97 | 18 | 1.15 | 1.16 | 1.33 | 27.5 | 1.20 | 1.19 |
| 1030 | 1,1-difluoroethane (R152a) | 113.26 | 18 | 0.79 | 0.79 | 0.90 | 18.9 | 0.82 | 0.79 |
| 1976 | Octafluorocyclobutane (RC318) | 115.23 | 11 | 1.34 | 1.33 | 1.52 | | | |
| 2200 | Propadiene | 120.85 | 22 | 0.50 | 0.51 | 0.57 | | | |
| 1021 | 1-chloro-1,2,2,2-tetrafluoroethane (R124) | 122.28 | 12 | 1.20 | 1.21 | 1.36 | | | |
| 1027 | Cyclopropane | 125.15 | 20 | 0.53 | 0.55 | 0.62 | 27.5 | 0.57 | 0.55 |
| 1033 | dimethyl ether | 126.95 | 18 | 0.58 | 0.58 | 0.65 | | | |
| 1026 | Cyanogens | 127 | 100 | 0.70 | 0.79 | 0.85 | | | |
| 1005 | Ammonia, Anhydrous | 132.25 | 33 | 0.53 | 0.55 | 0.58 | 56.8 | 0.56 | 0.54 |
| 3154 | Perfluoroethylvinylether | 127.85 | 10 | 0.98 | 1.22 | 1.42 | | | |
| 1969 | Isobutane | 134.67 | 10 | 0.49 | 0.49 | 0.56 | | | |
| 2517 | 1-chloro-1,1-difluoroethane (R142b) | 137.11 | 10 | 0.99 | 0.99 | 1.11 | 18.9 | 1.03 | 1.00 |
| 2202 | hydrogen selenide | 138 | 31 | 1.60 | 1.57 | 1.71 | | | |
| 2548 | chlorine pentafluoride | 142.85 | 13 | 1.49 | 1.61 | 1.77 | | | |
| 1063 | methyl chloride | 143.1 | 17 | 0.81 | 0.82 | 0.89 | 27.5 | 0.85 | 0.84 |
| 1017 | Chlorine | 144 | 22 | 1.25 | 1.25 | 1.37 | 56.8 | 1.30 | 1.25 |
| 1055 | Isobutylene | 144.75 | 10 | 0.52 | 0.53 | 0.59 | | | |
| 1958 | 1,2-dichloro-1,1,2,2-tetrafluoroethane (R114) | 145.68 | 10 | 1.30 | 1.31 | 1.46 | | | |

**Table 3. "Low Pressure" Fluids (Tc > 65˚C), continued.**

| UN Number | Name | $T_c$ ($^oC$) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 $^oF$, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 1012 | 1-butylene | 146.35 | 10 | 0.53 | 0.53 | 0.59 | | | |
| 1983 | 1-chloro-2,2,2-trifluoroethane | 156.85 | 10 | 1.18 | 1.19 | 1.31 | | | |
| 2197 | hydrogen iodide | 150.7 | 23 | 2.25 | 2.28 | 2.49 | | | |
| 1011 | Butane | 151.98 | 10 | 0.51 | 0.52 | 0.58 | | | |
| 1010 | 1,3-butadiene | 151.85 | 10 | 0.55 | 0.55 | 0.61 | | | |
| 1749 | chlorine trifluoride | 182.85 | 30 | 1.40 | 1.51 | 1.71 | | | |
| 1974 | Chlorodifluorobromomethane | 153 | 10 | 1.61 | 1.63 | 1.81 | | | |
| 1012 | trans-2-butylene | 155.45 | 10 | 0.54 | 0.54 | 0.60 | | | |
| 1086 | vinyl chloride | 158.85 | 12 | 0.81 | 0.82 | 0.90 | 18.9 | 0.85 | 0.84 |
| 1061 | methylamine | 156.9 | 13 | 0.58 | 0.59 | 0.63 | 18.9 | 0.61 | 0.60 |
| 1079 | Sulphur Dioxide | 157.49 | 14 | 1.23 | 1.23 | 1.33 | 18.9 | 1.28 | 1.25 |
| 1067 | nitrogen dioxide | 158 | 10 | 1.30 | 1.31 | 1.38 | | | |
| 1083 | trimethylamine | 160.1 | 10 | 0.56 | 0.57 | 0.63 | 18.9 | 0.59 | 0.57 |
| 2044 | 2,2-dimethylpropane | 160.65 | 10 | 0.53 | 0.53 | 0.59 | | | |
| 1012 | cis-2-butylene | 162.35 | 10 | 0.55 | 0.56 | 0.62 | | | |
| 1032 | dimethylamine | 164.05 | 10 | 0.59 | 0.59 | 0.64 | 18.9 | 0.62 | 0.59 |
| 1039 | ethyl methyl ether | 164.65 | 10 | 0.64 | 0.63 | 0.69 | | | |
| 1069 | nitrosyl chloride | 167.5 | 13 | 1.10 | 1.15 | 1.24 | 47.7 | 1.17 | 1.10 |
| 2196 | tungsten hexafluoride | 179.55 | 10 | 2.70 | 3.13 | 3.41 | | | |
| 1087 | vinyl methyl ether | 163.85 | 10 | 0.67 | 0.67 | 0.74 | 18.9 | 0.70 | 0.68 |
| 2676 | Stibine | 167.2 | 20 | 1.20 | 1.94 | 2.10 | | | |
| 1010 | 1,2-butadiene | 178.85 | 10 | 0.59 | 0.58 | 0.64 | | | |
| 1029 | dichlorofluoromethane (R21) | 178.43 | 10 | 1.23 | 1.24 | 1.35 | | | |
| 1741 | Boron trichloride | 178.8 | 10 | 1.19 | 1.20 | 1.31 | | | |
| 1076 | Phosgene | 181.85 | 20 | 1.23 | 1.24 | 1.35 | | | |
| 1036 | Ethylamine | 183 | 10 | 0.61 | 0.61 | 0.66 | | | |
| 1051 | hydrogen cyanide | 183.5 | 100 | 0.55 | 0.61 | 0.64 | | | |
| 2419 | bromotrifluoroethylene | 158.85 | 10 | 1.19 | 1.64 | 1.81 | | | |
| 2189 | dichlorosilane | 185.85 | 10 | 0.90 | 1.10 | 1.21 | | | |

**Table 3. "Low Pressure" Fluids (Tc > 65˚C), continued.**

| UN Number | Name | $T_c$ (°C) | $P_{test}$(bar) UN, gauge | Filling ratio UN | Filling ratio, UN, NIST | NIST: 130 °F, 3000 psig fill ratio | test P (bar) from CFR 173.304 | CFR 173.304 filling ratio NIST | CFR 173.304 filling ratio |
|---|---|---|---|---|---|---|---|---|---|
| 2601 | Cyclobutane | 186.78 | 10 | 0.63 | 0.63 | 0.69 | | | |
| 1037 | ethyl chloride | 187.2 | 10 | 0.80 | 0.81 | 0.88 | | | |
| 1052 | hydrogen fluoride | 188 | 10 | 0.84 | 0.83 | 0.87 | | | |
| 2452 | ethylacetylene | 166.85 | 10 | 0.57 | 0.59 | 0.64 | | | |
| 1062 | methyl bromide | 193.85 | 10 | 1.51 | 1.51 | 1.63 | | | |
| 1040 | ethylene oxide | 196 | 15 | 0.78 | 0.79 | 0.85 | | | |
| 1064 | methyl mercaptan | 196.8 | 10 | 0.78 | 0.79 | 0.85 | 29.3 | 0.82 | 0.80 |
| 1085 | vinyl bromide | 199.85 | 10 | 1.37 | 1.38 | 1.49 | | | |
| 1589 | cyanogen chloride | 175.85 | 20 | 1.03 | 1.06 | 1.14 | | | |
| 1745 | bromine pentafluoride | 213.85 | 10 | Na | 2.26 | 2.42 | | | |
| 2495 | iodine pentafluoride | 305.85 | 10 | Na | 2.95 | 3.14 | | | |
| 1746 | bromine trifluoride | 362.85 | 10 | Na | 2.49 | 2.63 | | | |
| | | | | | | | | | |
| 2901 | bromine chloride | | 10 | 1.50 | | | | | |

**Explanation of columns in Tables 2 and 3**

| | |
|---|---|
| 1. UN number. | The 4 digit UN identification number of the fluid. |
| 2. Name. | Chemical name of the fluid. |
| 3. $T_c$($^o$C). | The critical temperature, in $^o$C, recommended by NIST, as given in Table 1. |
| 4. $P_{test}$(bar). | The gauge test pressure, in bar, as given in the packing instruction P200, Table2 of UN Model regulation, Twelfth Edition. |
| 5. Filling Ratio, UN | The Filling Ratio as given in the packing instruction P200, Table 2 of UN Model regulation, Twelfth Edition. |
| 6. Filling Ratio UN, NIST | The Filling Ratio, f, computed by NIST.<br>a.) For high-pressure fluids, $f = \rho_F/\rho_{water}$. The fluid density $\rho_F$ is calculated from NIST databases at T=65 ˚C and $Ptest_{abs}$ (bar) where $Ptest_{gauge}=Ptest_{abs}-1$ and $\rho_{water}$=999.10262 g/L (the density of water at 15 ˚C, 0.101 325 MPa as given in Wagner, W. and Pruss, A., "The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use," J. Phys. Chem. Ref. Data, 31(2): 387-535, 2002.)<br>b.) For low-pressure fluids, $f = \rho_F/\rho_{water}$. The fluid density is calculated from NIST databases according to $\rho_F = 0.95\rho_{test}$ , where $\rho_{test}$ is evaluated at T=50 ˚C and P=min($Ptest_{abs}$ ,$P_{sat}$(T= 65˚C)) where $Ptest_{abs}$ is found as described in a.) and $P_{sat}$(T=65 ˚C) is the saturation pressure of the fluid calculated from a NIST database at T=65 ˚C expressed in bar (absolute). Check that $\rho_F$ is less than or equal to the saturation density of the fluid, calculated at T=60 ˚C using a NIST database. |
| 7. NIST, 130 $^o$F, 3000 psig | The filling ratio, computed by NIST, according to the 130 $^o$F, 3000 psig definition , $f = \rho_F/\rho_{water}$. In this case, $\rho_F$ is found using NIST databases at the conditions *T*=130 ˚F, *P*=3000 psig and $\rho_{water}$ = (1.0/27.737) lb/in$^3$ (water density supplied by sponsor). The same method is used for both high-pressure and low-pressure fluids. |
| 8. Test P (bar) from CFR 173.304 | Test pressure (in bar) from 49 CFR 173.304 computed in the following manner: For each $Ptest_{abs}$ in bar for fluids listed in P200, computed as described in column 4 above, determine a nominal service pressure $P_s$ = (3/5) $Ptest_{abs}$ and then convert this number to gauge units. Compare with service pressures in 49 CFR 173.304 and select closest one to nominal service pressure $P_s$. $P_{test}$ is then found with $P_{test}=(5/3)\ P_s$, using absolute pressure units. Test P is then reported in bar. |

| | |
|---|---|
| 9. CFR 173.304<br>Filling ratio<br>NIST | The filling ratio, computed by NIST, according to the definition, $f = \rho_F/\rho_{water}$. In this case, $\rho_F$ is found using NIST databases at T=130˚F, $P = P_{test}$ (bar) where the pressure is found as described in column 8 above. Check that $\rho_F$ is less than or equal to the saturation density of the fluid, calculated at *T*=130 ˚F using a NIST database. $\rho_{water}$ = (1.0/27.737) lb/in$^3$ (water density supplied by sponsor). |
| 10. CFR 173.304<br>Filling ratio | The filling ratio is computed by taking the maximum permitted filling density (percent) given in 49 CFR 173.304 divided by 100. |

## References for Table 1


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[3] Computing using EXCST model as implemented in NIST Standard Reference Database 4, National Institute of Standards and Technology, Gaithersburg, MD USA using recommended data from DIPPR Diadem v2.0, BYU (2000).
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