# Density and Viscosity of Aqueous Solutions of 1,3-Dimethylurea from (288.15 to 333.15) K

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# Density and Viscosity of Aqueous Solutions of 1,3-Dimethylurea from (288.15 to 333.15) K

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This work presents density and viscosity values for (1,3-dimethylurea + water) from (283.15 to 333.15) K for density and (288.15 to 333.15) K for viscosity at molalities up to 23.154 for both measurements. All measurements have been performed at atmospheric pressure. We have used a vibrating tube densimeter for the density measurements while we have used four different Cannon-Fenske viscosimeters for the viscosity measurements. We have calculated dynamic viscosities using the experimental densities.

## Introduction

1,3-Dimethylurea (DMU) is a compound of industrial and medical interest. It is used as a catalyst to obtain polymers and amines needed in the production of herbicides and drugs. Also, DMU has been used as a drug[1-4] because its cardio protective characteristics and its antioxidant effect. Different thermodynamic properties of aqueous solutions of DMU have been measured in the literature.[5-8] One reason to measure the thermodynamic properties is to explain hydrophobic effects and structure making/breaking actions. Jakli and Van Hook[6,7] measured the density of the aqueous solution of DMU at three temperatures from (288.15 to 308.15) K at molalities from (0.5 to 20) mol·kg$^{-1}$. Singh and Kumar[8] measured the density, viscosity, and surface tension also at three temperatures from (293.15 to 303.15) K at molalities from (0.005 to 0.25) mol·kg$^{-1}$. Phillip et al.[9] measured the density of DMU at 298.15 K from (0.05 to 6.35) mol·kg$^{-1}$.

In this work, we have measured the density of DMU from (283.15 to 333.15) K at molalities from (0.00329 to 23.1540) mol·kg$^{-1}$ using a vibrating tube densimeter. Also, kinematic viscosities of these mixtures have been measured using four different Cannon-Fenske viscosimeters from (288.15 to 333.15) K.

## Experimental Section

***Apparatus and Procedures.*** Explanation of the vibrating tube densimeter has been given before.[10] The reproducibility in the density and temperature measurement provided by the manufacturer are $\pm 1 \cdot 10^{-6}$ g·cm$^{-3}$ and $\pm 0.001$ K, respectively. The uncertainty of the density measurements and thermometer are better than $\pm 3 \cdot 10^{-5}$ g·cm$^{-3}$ and $\pm 0.01$ K on ITS-90, respectively. The densimeter was calibrated with ultrapure water and dry air by the manufacturer prior to beginning the experiment. Kinematic viscosities are measured using four different Cannon-Fenske viscosimeters, sizes 25, 50, 75, and 100 with flow ranges of (0.5 to 2)·10$^{-6}$ m$^2$·s$^{-1}$, (0.8 to 4)·10$^{-6}$
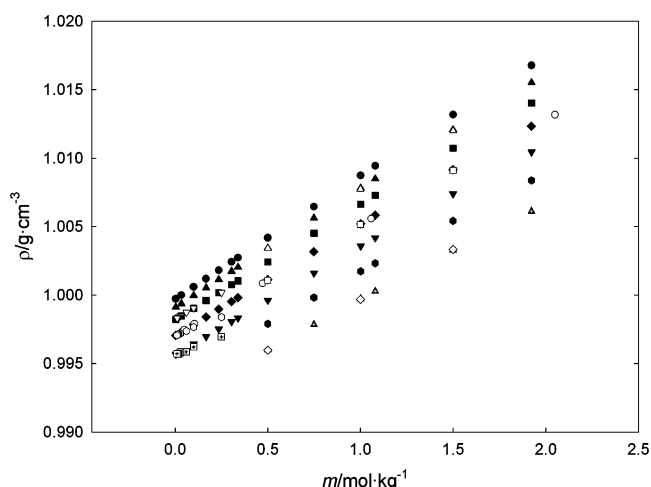


**Figure 1.** Comparison between experimental densities. Solid symbols, this work: ●, 283.15 K; ▲, 288.15 K; ■, 293.15 K; ◆, 298.15 K; ▼, 303.15 K; ⬟, 308.15 K; triangle with cross, 313.15 K. Hollow symbols literature values: Phillip et al.[9] ○, 298.15 K; Jakli and Van Hook[6] △, 288.15 K; □, 298.15 K; ◇, 313.15 K; Singh and Kumar[8] ▽, 293.15 K; ○, 298.15 K; ⊞, 303.15 K.

m$^2$·s$^{-1}$, (1.6 to 8)·10$^{-6}$ m$^2$·s$^{-1}$, and (3 to 15)·10$^{-6}$ m$^2$·s$^{-1}$, respectively. Measurements are performed following the ASTM 445 standard. The viscosimeters reside in a Polyscience constant-temperature water bath that is controlled within $\pm 0.01$ K. A digital thermometer F250 (automatic system) is used to measure the temperature with an uncertainty of 0.01 K. The efflux time is measured with an accuracy of 0.01 s. Each datum is an average of at least five runs with a maximum deviation in the kinematic viscosity of 6·10$^{-10}$ m$^2$·s$^{-1}$, and the estimated uncertainty in the dynamic viscosity is better than $\pm 0.004$ mPa·s.

## Samples

Water grade HPLC is supplied by Fischer Co. with a mole fraction purity greater than 99.95 %. DMU is provided from Aldrich with a stated mole fraction purity of 99.0 %. Pure

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**Table 1. Experimental Densities of Aqueous Solutions of DMU**

| | $\rho$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $m$ | g·cm$^{-3}$ | | | | | | | | | | |
| mol·kg$^{-1}$ | T/K = 283.15 | T/K = 288.15 | T/K = 293.15 | T/K = 298.15 | T/K = 303.15 | T/K = 308.15 | T/K = 313.15 | T/K = 318.15 | T/K = 323.15 | T/K = 328.15 | T/K = 333.15 |
| 0.0033 | 0.9997 | 0.9991 | 0.9982 | 0.9971 | 0.9957 | | | | | | |
| 0.0331 | 1.0000 | 0.9994 | 0.9985 | 0.9973 | 0.9959 | | | | | | |
| 0.0995 | 1.0006 | 1.0000 | 0.9990 | 0.9979 | 0.9964 | | | | | | |
| 0.1669 | 1.0012 | 1.0005 | 0.9996 | 0.9984 | 0.9970 | | | | | | |
| 0.2354 | 1.0018 | 1.0011 | 1.0002 | 0.9990 | 0.9975 | | | | | | |
| 0.3039 | 1.0024 | 1.0017 | 1.0008 | 0.9995 | 0.9981 | | | | | | |
| 0.3387 | 1.0027 | 1.0020 | 1.0010 | 0.9998 | 0.9983 | | | | | | |
| 0.4997 | 1.0042 | 1.0034 | 1.0024 | 1.0011 | 0.9996 | 0.9979 | 0.9960 | | | | |
| 0.7491 | 1.0065 | 1.0056 | 1.0045 | 1.0032 | 1.0016 | 0.9998 | 0.9979 | | | | |
| 1.0007 | 1.0087 | 1.0078 | 1.0066 | 1.0052 | 1.0036 | 1.0017 | 0.9997 | | | | |
| 1.0800 | 1.0094 | 1.0085 | 1.0073 | 1.0058 | 1.0042 | 1.0023 | 1.0003 | | | | |
| 1.4997 | 1.0132 | 1.0121 | 1.0107 | 1.0092 | 1.0074 | 1.0054 | 1.0033 | | | | |
| 1.9230 | 1.0168 | 1.0155 | 1.0140 | 1.0123 | 1.0105 | 1.0084 | 1.0061 | | | | |
| 2.8849 | 1.0246 | 1.0230 | 1.0212 | 1.0192 | 1.0171 | 1.0148 | 1.0123 | | | | |
| 4.0050 | 1.0326 | 1.0307 | 1.0285 | 1.0263 | 1.0238 | 1.0213 | 1.0186 | | | | |
| 5.3039 | 1.0407 | 1.0384 | 1.0359 | 1.0333 | 1.0306 | 1.0278 | 1.0249 | 1.0218 | 1.0186 | 1.0159 | 1.0123 |
| 6.8616 | 1.0487 | 1.0460 | 1.0433 | 1.0404 | 1.0374 | 1.0343 | 1.0311 | 1.0278 | 1.0245 | 1.0210 | 1.0175 |
| 8.7263 | 1.0563 | 1.0533 | 1.0502 | 1.0470 | 1.0438 | 1.0405 | 1.0371 | 1.0336 | 1.0301 | 1.0265 | 1.0227 |
| 11.0233 | 1.0634 | 1.0601 | 1.0568 | 1.0534 | 1.0498 | 1.0463 | 1.0428 | 1.0391 | 1.0354 | 1.0316 | 1.0278 |
| 15.6456 | 1.0725 | 1.0689 | 1.0653 | 1.0616 | 1.0578 | 1.0540 | 1.0502 | 1.0463 | 1.0424 | 1.0384 | 1.0344 |
| 23.1540 | 1.0796 | 1.0757 | 1.0719 | 1.0680 | 1.0640 | 1.0601 | 1.0561 | 1.0521 | 1.0480 | 1.0439 | 1.0398 |

**Table 2. Experimental Viscosities of Aqueous Solutions of DMU**

| | $\eta$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $m$ | mPa·s | | | | | | | | | |
| mol·kg$^{-1}$ | T/K = 288.15 | T/K = 293.15 | T/K = 298.15 | T/K = 303.15 | T/K = 308.15 | T/K = 313.15 | T/K = 318.15 | T/K = 323.15 | T/K = 328.15 | T/K = 333.15 |
| 0.0033 | 1.1730 | 1.0348 | 0.9187 | 0.8242 | | | | | | |
| 0.0331 | 1.1874 | 1.0451 | 0.9290 | 0.8316 | | | | | | |
| 0.0995 | 1.2116 | 1.0656 | 0.9456 | 0.8464 | | | | | | |
| 0.1669 | 1.2324 | 1.0811 | 0.9603 | 0.8592 | | | | | | |
| 0.2354 | 1.2427 | 1.0937 | 0.9716 | 0.8702 | | | | | | |
| 0.3039 | 1.2550 | 1.1042 | 0.9789 | 0.8753 | | | | | | |
| 0.3387 | 1.2701 | 1.1174 | 0.9944 | 0.8870 | | | | | | |
| 0.7491 | 1.4017 | 1.2279 | 1.0835 | 0.9652 | 0.8666 | 0.7797 | | | | |
| 1.9230 | 1.8307 | 1.5811 | 1.3787 | 1.2162 | 1.0788 | 0.9649 | | | | |
| 2.8849 | 2.2251 | 1.9022 | 1.6485 | 1.4400 | 1.2708 | 1.1267 | | | | |
| 4.0050 | 2.7461 | 2.3254 | 1.9977 | 1.7294 | 1.5113 | 1.3357 | | | | |
| 5.3039 | 3.3425 | 2.8047 | 2.3817 | 2.0551 | 1.7783 | 1.5599 | 1.3796 | 1.2221 | 1.0953 | 1.0245 |
| 6.8616 | 4.1789 | 3.4639 | 2.9208 | 2.4905 | 2.1347 | 1.8591 | 1.6320 | 1.4401 | 1.2931 | 1.1641 |
| 8.7263 | 5.2421 | 4.2697 | 3.5351 | 3.0025 | 2.5451 | 2.1951 | 1.9062 | 1.6811 | 1.4923 | 1.3432 |
| 11.0233 | 6.5334 | 5.2621 | 4.3418 | 3.6034 | 3.0564 | 2.6264 | 2.2676 | 1.9833 | 1.7599 | 1.5644 |
| 15.6456 | 9.3002 | 7.3769 | 5.9546 | 4.9275 | 4.1157 | 3.5134 | 3.0244 | 2.6460 | 2.3334 | 2.0606 |
| 23.1540 | 14.4876 | 11.2221 | 8.7998 | 7.1224 | 5.8651 | 4.9178 | 4.1955 | 3.6575 | 3.2115 | 2.8178 |

components are used as received. The mixtures are prepared gravimetrically using an analytical balance (Ohaus Model AS120S) with a precision of ± 0.1 mg. The overall uncertainty in the molalities is better than ± 8·10$^{-5}$ mol·kg$^{-1}$.

## Results and Discussion

The density of aqueous solutions of DMU have been measured from (283.15 to 333.15) K at atmospheric pressure and at molalities from (0.00329 to 23.154) mol·kg$^{-1}$. The calibration of the densimeter is verified after each mixture is measured. Its calibration is considered satisfactory if the measured water density is within ± 0.005 kg·m$^{-3}$ of the values given by Bettin and Spieweck.[11] Table 1 shows the experimental density values for the DMU aqueous solutions. At high molalities, our results have been compared with those of Jakli and Van Hook[6] and Phillip et al.,[9] while at low concentrations we compared our results with values of Singh and Kumar.[8] The relative agreement between our experimental values and the densities from Jakli and Van Hook[6] and Phillip et al.[9] is within 0.009 % and 0.028 %, respectively. At low molalities, values from Singh and Kumar[8] agree with our densities within an average percentage deviation of 0.06 %. A plot of the densities as a function of the molality shows clearly that densities measured by Singh and Kumar[8] scatter from the rest of the data. The highest discrepancy occurs at 293.15 K as shown in Figure 1. Experimental densities reported by Pandey et al.[12] do not agree with the literature values and densities from this work. Brown et al.[13] suggested that this difference could be due to dehydration in Pandey's sample. Therefore, they have not been included in this work. Although the values from Brown et al.[13] were taken at 0.35 MPa, our measurements agree with their values within 0.02 %. Lo Surdo et al.[14] measured the density of DMU solutions at 298.15 K at molalities up to 1.15 mol·kg$^{-1}$. Their density measurements agree with ours within 0.002 %.

With respect to the viscosity values, to the best of our knowledge, there are no experimental measurements at high molalities. The only available data are those of Singh and Kumar[8] at three temperatures (293.15, 298.15, and 303.15) K and at molalities lower than 0.25 mol·kg$^{-1}$. Figure 2 shows a comparison between our measurements (Table 2) and their
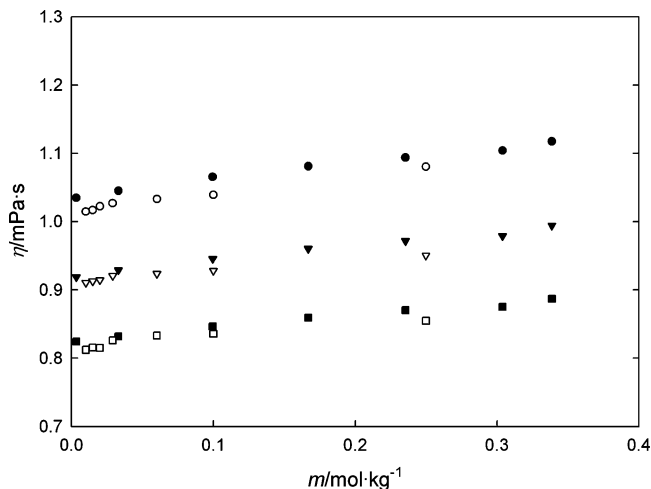
**Figure 2.** Comparison between experimental viscosities. Solid symbols, this work: ●, 293.15 K; ▼, 298.15 K; ■, 303.15 K. Hollow symbols are from Singh and Kumar:[8] ○, 293.15 K; ▽, 298.15 K; □, 303.15 K.

values. Their values are lower than ours, and the agreement is within an average percentage deviation of 1.8 %. At lower molalities the scatter of their values is higher.

## Conclusions

Liquid densities of aqueous solutions of DMU have been measured from (283.15 to 333.15) K at molalities up to 23.154 mol·kg$^{-1}$. Our new measurements agree with literature values of Jakli and Van Hook.[6] Also, the viscosities of the same solutions have been measured at temperatures between (288.15 and 333.15) K. We have not found experimental values at molalities higher than 0.25 mol·kg$^{-1}$ in the literature. At lower molalities our measurements agree with the literature values within 1.8 %.

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