



# Viscosity measurements of *ortho*-xylene, *meta*-xylene, *para*-xylene and ethylbenzene



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## ABSTRACT

The compressed liquid viscosities of *ortho*-xylene, *meta*-xylene, *para*-xylene and ethylbenzene were measured using a vibrating-wire viscometer at different temperatures and pressures. The measurements were performed over the temperature ranges of (273 to 373) K for *o*-xylene and *m*-xylene, (293 to 373) K for *p*-xylene and (253 to 373) K for ethylbenzene, at pressures from (0.1 to 30) MPa, except for ethylbenzene for which the pressure range was up to 35 MPa. The combined expanded uncertainty of the reported viscosity is better than 2% with a confidence level of 0.95 ( $k = 2$ ). The experimental data were correlated with the empirical Andrade–Tait equation which reproduced the results with the average absolute percentage deviations of (0.25, 0.15, 0.16 and 0.23)% for *o*-xylene, *m*-xylene, *p*-xylene and ethylbenzene, respectively. The present results are in good agreement with most of the literature values.

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## 1. Introduction

The xylene family consists of three isomers of dimethyl benzene which are distinguished by the designations of *ortho*-(*o*-)xylene, *meta*-(*m*-)xylene, and *para*-(*p*-)xylene. Ethylbenzene, which has the same chemical formula  $C_8H_{12}$  and consists of a benzene ring with an additional ethyl group is commonly considered as the fourth isomer [1]. Xylene isomers are colorless, sweet-smelling liquids occurring naturally in crude oil and are also found in gasoline and to some extent kerosene. Xylenes, that are the basis for the synthesis of many organic compounds, are of great importance as raw materials and solvents in the petrochemical industry and in medical applications. They are normally produced as a mixed stream that contains *o*-xylene, *m*-xylene, *p*-xylene, and ethylbenzene. It is difficult to efficiently separate these aromatic compounds due to their low relative volatility and the high degree of purity required for the final products [2].

In order to simulate and optimize the separation process, along with many other chemical engineering operations, one needs thermodynamic and transport property data. There is thus a growing industrial need to establish reference values of thermophysical properties of pure fluids that are both accurate and thermodynamically consistent [3]. Furthermore, the values of pure fluids also

serve as the starting point for the prediction of thermophysical properties of mixtures. For example, the well-developed Vesovic and Wakeham (VW) method that can be used to predict accurately the viscosity of a variety of different mixtures, relies on obtaining the effective parameters for mixtures from a knowledge of the viscosity of pure species [4,5].

At present, no viscosity correlation covering the wide ranges of temperature and pressure for xylene isomers is available. The only exception is *p*-xylene for which a reference correlation of viscosity was reported recently by Balogun *et al.* [6]. The development of an accurate correlation relies on having the best available experimental data. Hence, measurements of the viscosity of *o*-xylene, *m*-xylene and ethylbenzene over the wide temperature and pressure ranges reported in the present work will also serve as input data for developing the viscosity correlations for these xylene isomers.

## 2. Experimental

### 2.1. Chemicals

The sources of the samples were as follows: *o*-xylene and ethylbenzene were supplied by Thermo Fisher Scientific Inc. with a mass fraction purity of 0.99 and 0.998, respectively; *m*-xylene was supplied by Alfa Aesar (China) Chemicals Co. Ltd. with a mass fraction purity of 0.99; and *p*-xylene was supplied by Aladdin

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**TABLE 1**  
Specification of chemical samples.

Chemical name	CAS number	Source	Initial mass fraction purity
<i>o</i> -Xylene	95-47-6	Thermo Fisher Scientific	0.99
<i>m</i> -Xylene	108-38-3	Alfa Aesar	0.99
<i>p</i> -Xylene	106-42-3	Aladdin	0.99
Ethylbenzene	100-41-4	Thermo Fisher Scientific	0.998

Industrial Corporation with a mass fraction purity of 0.99. All of the sample purities were specified by the suppliers, and no further analysis or purification was attempted. A full specification of the samples is given in table 1.

## 2.2. Apparatus

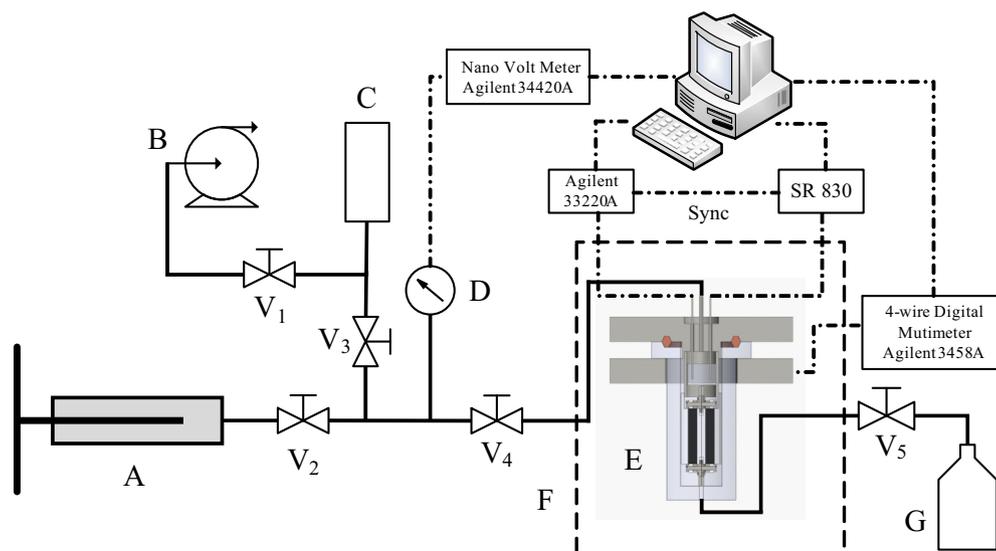
The vibrating-wire viscometer is used to measure the viscosity of fluids over wide temperature and pressure ranges, because of its simplicity, rigorous mathematical description and well-established working equations. The theory that describes the motion of a wire within a fluid has been reviewed by Retsina *et al.* [7,8], Padua *et al.* [9], and Kandil *et al.* [10]. In this work, the viscosity was measured using the experimental arrangement where both ends of the wire were clamped in a steady state vibrating-wire viscometer which has been described, in detail, previously [11,12]. The viscometer consists of a tungsten wire, supplied by Metal Cutting, with a nominal radius of  $(50.00 \pm 0.32) \mu\text{m}$  and a nominal length of 58 mm, a pair of samarium–cobalt magnets with a length of about 40 mm, and a custom-made stainless steel vessel with a maximum design pressure of 70 MPa. The wire, subject to a permanent magnetic field, was driven to transverse oscillation by introducing a sinusoidal voltage generated by a function generator (model: 33220A, Agilent). An electromotive force is induced at the wire ends in response to the wire's velocity of oscillation, which is related to the viscosity and density of the fluid. The in-phase and quadrature voltages across the wire were detected with the lock-in amplifier (model: SR830, Stanford Research Systems) over the frequency range  $(f_r \pm 5g)$ , where  $f_r$  is the resonance frequency, and  $g$  is the half-width of the resonance curve. For each fluid at a given temper-

ature and pressure, the measured complex voltages were analyzed according to the working equations and a value of the viscosity of the fluid was obtained. The calibration and validation of the present apparatus has been described in our previous work [11], and it was used in this work without any changes. A diagram of the experimental system is shown in figure 1.

A thermostatic bath was used to maintain the constant temperature of the apparatus. The temperature was measured with a calibrated  $100 \Omega$  platinum resistance thermometer connected to a DMM (model: 3458A, Agilent). The combined expanded uncertainty of temperature with level of confidence 0.95 ( $k=2$ ) is  $U_c(T) = 12 \text{ mK}$ . The pressure was generated with a manual piston pump (model: 50-6-15, HIP) and measured by a high pressure transducer (model: P3MB, HBM) with a pressure range up to 100 MPa. A nanovolt meter (model: 34420A, Agilent) with  $7^{1/2}$  digits resolution was employed for the transformation of the pressure transducer measurement signal. The combined expanded uncertainty of pressure  $U_c(p) = 0.12 \text{ MPa}$  ( $k=2$ ). Taking into account the uncertainties of temperature and pressure, repeatability of measurements, regression procedure and the density of fluid, the combined expanded uncertainty of viscosity with level of confidence 0.95 ( $k=2$ ) is estimated to be better than 2%.

## 3. Results and correlations

Knowledge of the accurate value of density of the fluid is essential in order to obtain the viscosity from the working equations of the vibrating-wire viscometer [10]. The density values of *o*-xylene, *m*-xylene, *p*-xylene and ethylbenzene at a given temperature and pressure were calculated using the equations of state (EOS), developed by Zhou *et al.* [1] for each xylene isomer. Uncertainties in density of *o*-xylene, *m*-xylene, *p*-xylene and ethylbenzene are estimated to be better than (0.1 to 0.2)% in the liquid region, at the temperature and pressure of interest to this work. Viscosity measurements of *o*-xylene and *m*-xylene were performed along 11 isotherms over the temperature range of (273 to 373) K and at pressures from (0.1 to 30) MPa. The viscosities of *p*-xylene were measured at pressures from (0.1 to 30) MPa, along 9 isotherms from  $T = (293 \text{ to } 373) \text{ K}$ . With regard to ethylbenzene, the viscosity measurements were carried out along 13 isotherms from  $T = (253 \text{ to } 373) \text{ K}$  and at pressures from (0.1 to 35) MPa. The experimental



**FIGURE 1.** Schematic diagram of experimental system: (A) manual piston pump; (B) vacuum pump; (C) sample container; (D) pressure transducer; (E) vibrating wire viscometer; (F) thermostatic bath; (G) wasting recycle; (V1–V5) valves.

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