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**SOLUBILITIES OF SUBSTITUTED PHENOLS IN  
SUPERCRITICAL FLUID CARBON DIOXIDE**

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# Introduction

In recent years, there has been increased interest in supercritical fluid (SCF) technology. SCF extractions/separations are utilized in industry for various processes.

The unique feature of supercritical fluids is that the solvent power strongly depends on the fluid density, which can be adjusted by controlling the temperature and pressure.

Carbon Dioxide (CO<sub>2</sub>) is a commonly used supercritical solvent because of its low cost and its non-toxicity. Its industrial and analytical importance lies in the convenient critical parameters (31.1°C and 73.8 bar)

Substituted phenols are an important class of compounds having widespread use (germicides, disinfectants, ingredients in fuel, etc.) There is little information in the literature regarding the solubilities of phenols in SCF CO<sub>2</sub>. Accurate and precise solubility data for the compounds of interest is essential for the design of any SCF-based process.

In this work, the solubilities of selected substituted phenols (2,5-dimethylphenol, 2,4,6-trimethylphenol, 2,3,5-trimethylphenol, 4-phenylphenol, 4-tert-butylphenol) in binary (single solute + SCF CO<sub>2</sub>) and ternary (two solutes + SCF CO<sub>2</sub>) systems were investigated.

## **Experimental Method**

**A schematic diagram of the apparatus is shown in Figure 1. The apparatus was designed and built in-house (Fig 2). A microsampling technique with a dynamic flow of CO<sub>2</sub> was used to evaluate the solubility of the test solutes.**

### **Procedure**

**An important feature of the apparatus is the use of two 6-port switching valves (Fig 3.) The first switching valve is used to direct the flow of the supercritical CO<sub>2</sub> either through the equilibration cell containing solute/solutes or to bypass the cell and purge the rest of the system. The second switching valve is used as a sampling valve.**

**Switching of the sampling valve allowed for the escape of a fixed volume of the saturated SCF solution from the sample loop into a trapping solvent. Solvent is pumped through the sample loop and sampling valve to flush any precipitated solutes into the trapping solvent. The trapping solvent is then diluted to a known volume in preparation for analysis.**

## Chromatographic conditions

Detection	UV-265/280 nm
Separation column	Spherisorb ODS 2, 5 $\mu$
Mobile Phase	0.01M $\text{KH}_2\text{PO}_4$ :MeOH (40:60); 1mL/min flow rate

Solubility of the solutes is expressed as mole fraction solubility(y)

$$y = \frac{\text{number of moles of the solute}}{\text{total moles of saturated solution in sampling loop}} *$$

Area-concentration curves were used to determine the concentration of the collected analytes. A new calibration curve was made each time an analysis of sample solutions was conducted.

Individual solubilities were determined by taking an average of at least three replicate measurements made on separate days. The reproducibility of the results was generally  $\pm 5\%$  or less.

\*approximated as moles of  $\text{CO}_2$

## **Results and Discussion**

### **Validation**

The reliability and accuracy of our solubility measurement technique was previously established by measuring the solubility of naphthalene in CO<sub>2</sub>.<sup>1</sup> The validity of the solubility data was reconfirmed by comparing the binary solubility of 2,5-dimethyl phenol with that reported by Iwai et al.<sup>2</sup>

### **Binary solubility**

Binary solubilities of 2,5-dimethylphenol (2,5-DMP), 2,4,6-trimethylphenol (2,4,6-TMP), 2,3,5-trimethylphenol (2,3,5-TMP), 4-phenyl phenol (4-PP), and 4-tert-butylphenol (4-tBuP) were measured at 308 K over a range of pressures (101-280 bar).

### **Ternary solubility**

It has been observed that in mixed solute systems the solubility of the components in SCFs may be considerably different from their respective binary solubilities.<sup>3</sup> Recent studies on polar multicomponent systems have indicated solubility enhancements, which could be associated with strong solute-solute interactions such as hydrogen bonding.<sup>1,4</sup> Solubility enhancements usually follow a pattern where solubility of one component is enhanced in proportion to the solubility of the other component in the ternary system<sup>5</sup> (entrainer effect).<sup>6</sup>

Three ternary systems 4-PP and 2,3,5-TMP; 4-PP and 2,4,6-TMP; and 2,5-DMP and 4-tBuP were investigated at 308 K over a range of pressures.

## **Discussion**

### **Binary solubility**

Binary solubilities of substituted phenols ranged from  $10^{-5}$ - $10^{-2}$  mole fraction and varied in the following order- 2,4,6-TMP > 2,5-TMP > 4-tBuP > 2,3,5-TMP > 4-PP. Binary solubilities show a regular trends of increased solubility with increased pressure (solvent density).

### **Ternary solubility**

The ternary systems of 2,3,5-TMP/4-PP and 2,4,6-TMP/4-PP conform to the entrainer effect, with 4-PP showing enhancements up to 21% and 233%, respectively, while no enhancement occurred with the two other solutes. The ternary system of 2,5-DMP/4-tBuP exhibited an unusual behavior where the solutes had more than 1000% solubility enhancement while the individual solubilities decreased with increased pressure. This degree of solubility enhancement is very uncommon in mixed solid systems. There could be a possible shift in the LCEP of this mixture from the critical point of pure SCF CO<sub>2</sub>. This ternary system is still under investigation.

### **Technical difficulties**

The micrometering valve, which serves as a pressure reducer, was heated to minimize solute plugging. Though the heated valve worked effectively for most of our solutes, in cases of extremely high solubility plugging problems were frequent, which led to poor reproducibility in our solubility measurements.

## **Phase Behavior**

**The phase behavior of organic solids in CO<sub>2</sub> can be quite complex. Pure solids may undergo depression in melting point under the influence of high pressure CO<sub>2</sub>,<sup>7</sup> which could be more significant in mixed solute systems<sup>8</sup>. In order to ensure that only solid-fluid equilibrium conditions exist, we visually check the lower critical end point (LCEP)<sup>9</sup> and the possible depression in the melting point of solutes in SCF CO<sub>2</sub>. The LCEP of solute systems is usually very close to the critical point of pure SCF, which is characterized by critical opalescence.**

### **Experimental section**

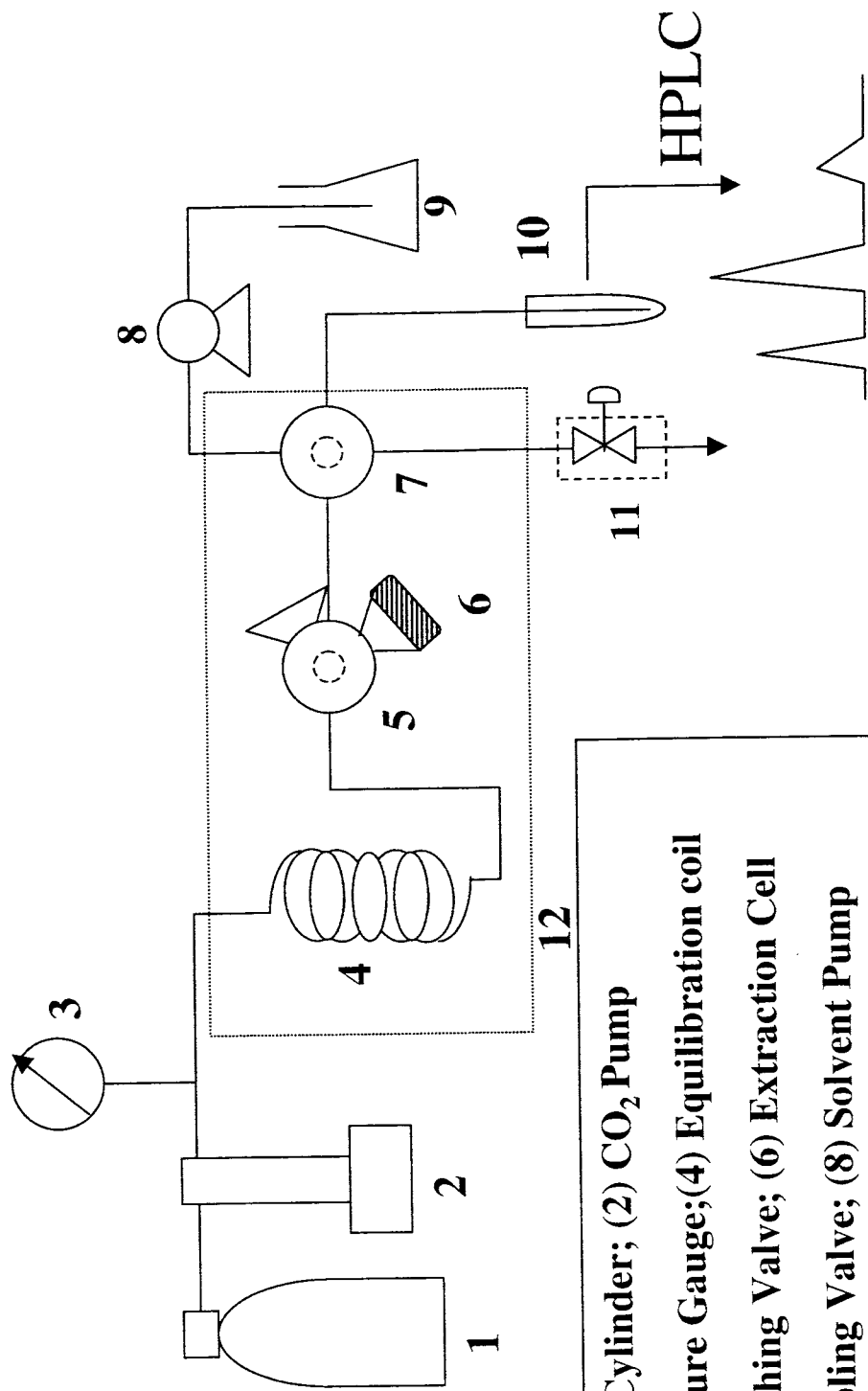
**The SFT Phase Monitor (Supercritical Fluid Technologies, Inc.) consists of a variable-volume view cell equipped with quartz windows, a movable piston, a mixer, a variable focus video camera, and a monitor (Fig 4.)**

**To check for melting, the solute was placed in the view cell and the system was pressurized slowly at 308 K to the maximum pressure used in this work.**

**No depression in the melting point was observed in any of the systems investigated. The LCEP determinations of the solute systems are in progress.**

## References

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- (1) CO<sub>2</sub> Cylinder; (2) CO<sub>2</sub> Pump
- (3) Pressure Gauge; (4) Equilibration coil
- (5) Switching Valve; (6) Extraction Cell
- (7) Sampling Valve; (8) Solvent Pump
- (9) Solvent Reservoir; (10) Analyte Collection
- (11) Heated Micrometering Valve
- (12) Oven

**FIGURE 1: SCHEMATIC OF SFE APPARATUS**

