MEASUREMENT OF PVT PROPERTIES OF WOOD-PLASTIC COMPOSITES

M. Golzar*, **N. Sadeghian**

Manufacturing Engineering Group, Mechanical Engineering Department,
Tarbiat Modares University, P.O.BOX 14115-143, Tehran, Iran
Telephone: +98 21 88011001, Fax: +98 21 88005040

*Corresponding author E-mail: m.golzar@modares.ac.ir

Keywords: *PVT, WPC, Rheology, Volume flow rate*

Abstract

In present paper, PVT (Pressure, specific Volume and Temperature) properties of plastic materials in pure and solution are reviewed. The PVT measurements are mainly investigated for thermoplastic composites melt such as Wood-Plastic Composites (WPC). The PVT properties aided two methods are carried out using on-line measurement: One method is using a capillary die and the second one is using a gear pump in extrusion line. The measurements can be used in extrusion line and die design. Rheology behavior of melt state of WPCs is studied in order to use the viscosity is to estimate the specific volume. Results show good agreement between two methods and can be used for other polymeric composites. Also, WPCs density in solid state achieves by rule of mixture and theatric data and measured values have good agreement. Finally compressibility and volume thermal expansions of WPCs can be achieved for Tait Equations

1 Introduction

Wood plastic composites (WPC) have received considerable attention during the past two decades due to their many advantages such as low cost, significant strength and stiffness, moisture, abrasion and insect resistance. As the wood fillers are widespread and renewable raw materials, WPC continue attracting the attention of researchers and technologists.

New WPC products are mainly manufactured aided extrusion and recently the injection molding are considered [1]. Such thermoplastic composite manufacturing process is encountered high dimension variations. The dimension variations due to temperature and pressure can lead to undesirable contraction and distortion of parts. Therefore to manufacture perfect WPC products with fine tolerance the PVT diagrams are used definitely.

This research based on measurement of PVT properties of WPCs in certain concentrations and can be applied for filled polymers and particulate polymeric composites. As mentioned above these measurements are of great importance for design and production. PVT properties of polymeric and plastic materials in pure and solution are reviewed and the measurements of polymeric composites are investigated in the literature. For WPC no PVT references for production and manufacturing processing stages is reported.

2 Theories

Other attempts for measurement and development of models and empirical relations to determine the PVT properties of polymeric materials have been studied [2]. Also, standard test methods according ASTM test procedures have been achieved and presented in related literature entitled by “Dilatometry” for solid state [3]. In the other hand, all of available methods are laboratory and low speed measuring units and also so expensive and no suitable for industrial and processing conditions. All of them are Off-line equipments. The method introduced and used in this paper are quick and best fitted to processing conditions. The two methods can be used On-line in an extrusion line.

2.1 Melt state of WPC

For melt state two innovations experimental systems to measure PVT properties of wood-plastic composites is presented briefly. These systems based on determining of volume and mass flow rates through an extruder at specific temperature and pressures. Mass flow rate is measured via weight of extrudate mass at specific time through small diameter capillary [4]. By dividing volume flow rate to measured mass flow rate specific volume shall be achieved [5]:

$$v = \frac{Q}{\dot{m}} \tag{1}$$

For determining volume flow rate two methods presents: Capillary die and Gear pump.

2.1.1 Capillary die

By using capillary die the volume flow rate can be found by measuring the pressure drop and the relationship of pressure–volume flow rate [6]. Capillary features and nomenclatures illustrated in Figure 1.

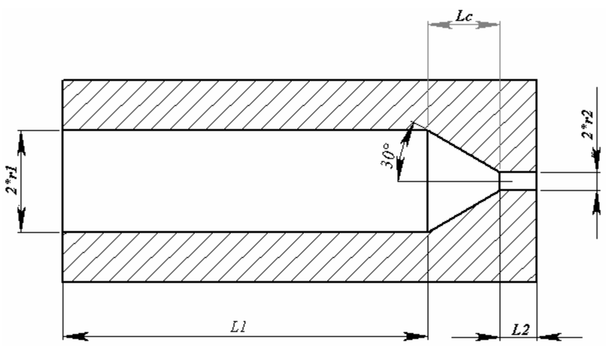

Figure1 Capillary shape and nomenclature

The pressure drop in capillary flow is a function of volume flow rate, flow behavior of composite and geometry of capillary. Pressure drop in a capillary die in Figure 1 consists of two sections: conic and capillary sections. The pressure drop in laminar flow can be presented as [4, 6]:

$$\Delta P_{Capillary} = \frac{2.L.K}{r^{3n-2}.\left[n.\pi(3n+1)^{1/n}\right]^{n-1}}.(\tag{2}$$

$$\Delta P_{Conic} = \frac{2K}{3n.\tan\alpha}\left(\frac{3n+1}{n.\pi.r_2^3}\right)^n.\left[1-\left(\frac{r_2}{r_1}\right)^{3n}\right] \tag{3}$$

The total pressure drop is the sum of above mentioned Equations (2) and (3). The total pressure drop is summarized in Equation (4).

$$\Delta P = A.R.Q + B.Q^n \tag{4}$$

Which coefficients A, B and R can be calculated regarding to die geometry, flow model parameters. The volume flow rate in Equation (4) can be obtained numerically as a function of pressure drop. Also Equation (4) can be plotted if the coefficients A, B and R were determined. If the volume flow rate over pressure drop shows linear region, a linear relation fitted to Equation (4) can be used as indicated in Figure 2.

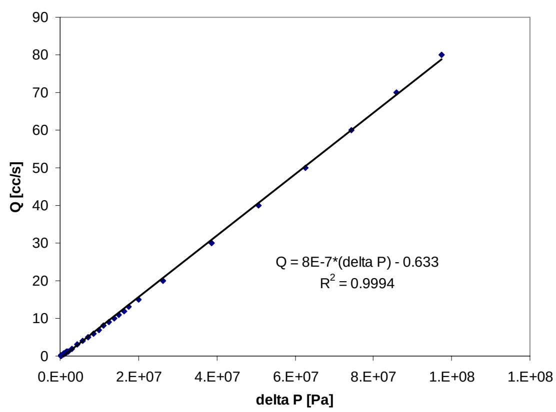

Figure 2 volume flow rate- pressure drop in a capillary die at linear region

In order to model the WPC flow behavior in the capillary die an optimized power law model can be assumed as Herschel- Buckley [7, 8].

$$\begin{aligned} &\tau = \tau_Y + K.\dot{\gamma}^n && \text{for} && |\tau| \geq |\tau_Y| \\ &\dot{\gamma} = 0 && \text{for} && |\tau| < |\tau_Y| \end{aligned} \tag{5}$$

The parameters K and n shall be used to determine the volume flow rate in Equation (2) to (4).

2.1.2 Gear pump

Other way to measure the volume flow rate is using the gear pump [5]. Melt extrudate was first entering to a gear pump. By fixing pressures at inlet and outlet of gear pump we can use the gear pump as a measurement device for volume flow rate by multiplying volumetric characteristics of pump in rotation speed.

Pump characteristics can be determined from another experiment. Considering a gear pump as a control volume and writing Bernoulli equation between inlet and outlet of pump we have [4]:

$$\frac{P_1}{\rho . g} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\rho . g} + Z_2 + \frac{V_2^2}{2g} \qquad (6)$$

And by continuum equation we have:

$$Q = V.S = Const. \qquad (7)$$

From these relations a linear equation between displaced volume and rotation speed of pump shall achieve. Pump calibration result chart presented in Figure 3. Data from experimental and pump supplier have 5.5 percent error and we use experiments results in our calculations.

2.2 Solid state of WPC:

To determine the PVT properties of composite materials from theoretical point of view, the “rule of mixture” is investigated in solid state. Solid state density of WPC by role of mixture

$$\rho_c = \rho_f . v_f + \rho_m . (1 - v_f) \qquad 8)$$

relation is:

3 Experimental

3.1. Material

The thermoplastics used are High Density Polyethylene as resin phase and Wood powder as reinforcement phase. Raw materials and derived WPCs presented in Table 1. the WPCs are produced as granulate and then were used in the measurements.

Wood powders from recycling matters and approximation dimensions are indicated in Figure 4. Figure 5 shows the size of particle frequency.

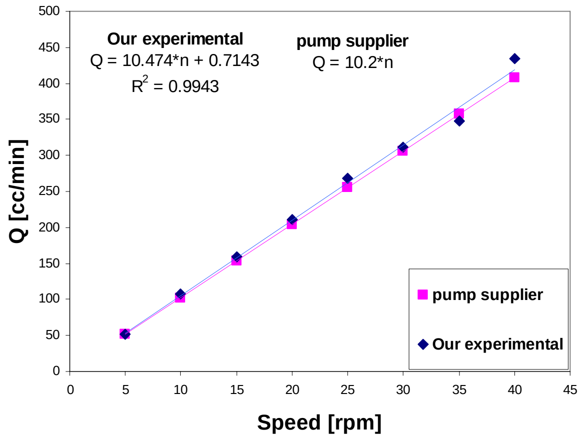

Figure 3 gear pump calibration and comparison

Table 1 Raw thermoplastic and WPCs derived

Materia ls	Grade	Supplier	MFI@ 170°C, 600 s, 2.16 kg	Density
HDPE	I-2	Arak Petrochem ical complex	8.080 [b]	0.956
HDPE	5620E A	Arak Petrochem ical complex	---	0.954
HDPE	5216E A	Arak Petrochem ical complex	16 @ 190°C	0.952
20%w-WPC	---	---	---	1.06
40%w-WPC	---	---	2.025	1.09

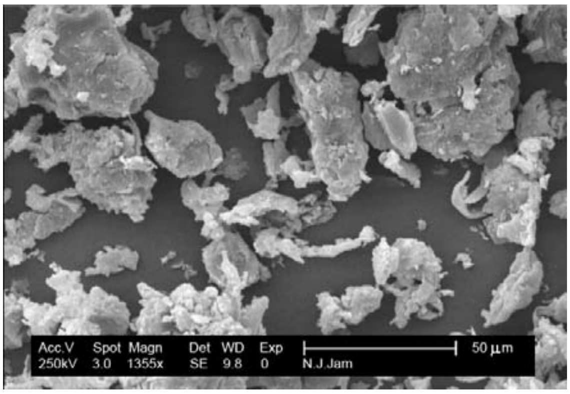

Figure 4 wood powder dimensions

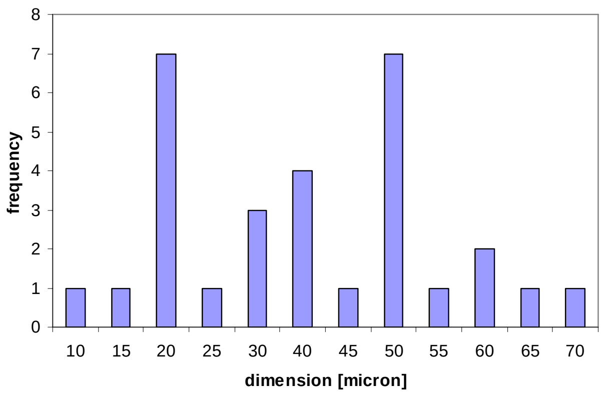

Figure 5 wood powder size frequency

3-2- Equipments

In five separate experimental sets we use some devices as presented and summarized in Table 2. These five experiments are:

pellet preparation or granulation

rheometry

capillary dilatometry

gear pump calibration

gear pump dilatometry

Schematic and designed views of executed dilatometry setups for capillary dilatometry are shown in Figures. 5 to 7 respectively.

Table 2 Equipments in experimental

Name of element	Characteristics	Model	Manufacturer
Extrusion set	Twine screw extruder	Co-rotating screws, $\frac{L}{D}=21$	Tarbiat Modares University
Temperature controller	PID controller	MX9-FKMNNN	Hanyoung -Korea
Pressure gauge	Modified to melt pressure gauging	0-400 bar	WIKA-Germany
Rheometer	Parallel disks	USD200	Paar physica-China
Chopper	Plastic Granulator	HSS 180	Ningbo Huare Machinery-China
Gear pump	Cinox/Therminox	28/28	Maag-textron, Switzerland
Oil heating system	Automatic mold temp. controller	HCM-05LD	Ningbo Huare Machinery-China
Digital	Acc. 0.01 gr		-Japan
Digital	Acc.1 gr		-Korea
Chronometer watch	Stop watch	2519 - A178W	Casio-Japan
Ball valve	Pressure adjusting	Carbon steel body	---
Electro-gearbox	Drive motor-Gear box	MR203-90S/4	Yilmaz-Turkey
Inverter	Speed controller	VFD015 M21A	Delta-Taiwan
Temperature sensor	Temperature transducer	MN2-6-MB01M-1-4-D	Gefran-Italy

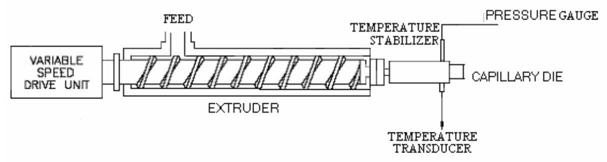

Figure 6 Schematics of capillary dilatometry for WPCs

Figure 7 View of executive setup for capillary dilatometer

4. Results Discussions

The experiments regarding the flow of composite could be used to optimize the power-law model and predict the WPC rheological behaviors [٩]. The parameters of model (*K and n*) are found and presented in Table 3. As investigate [١٠] the *K* parameter increases by increasing the wood content

Also, rheological behavior of samples illustrated and compare in Figure 8 and Figure 9. As indicate in Figure 9 increasing viscosity by increasing in wood content and this shift isn't linearity. In categorizing of WPCs melt, non-Newtonian fluid with yield stress (Figure 8) achieved by categorization mentioned in reverences [7].

Sample	Shear rate [1/s]	Power Law parameters	
		K	n
40%w-WPC	0.1 to 30	2500	0.8700
20%w-WPC	0.1 to 6	1620	0.7479
HDPE-I2	0.1 to 100	1474	0.9412

Table 3 Parameters of Power-Law model

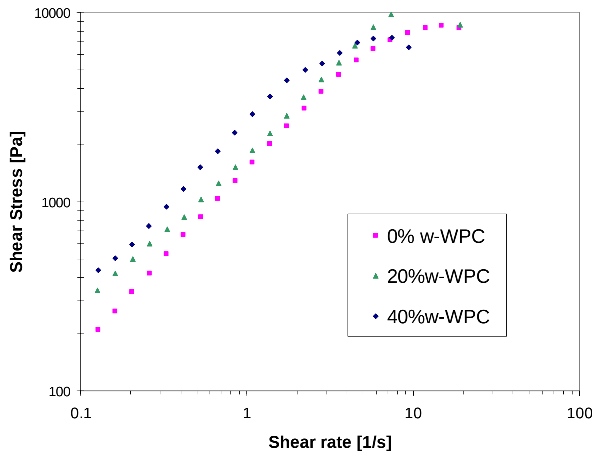

Figure 8 Flow behaviors of WPC samples at 180°C

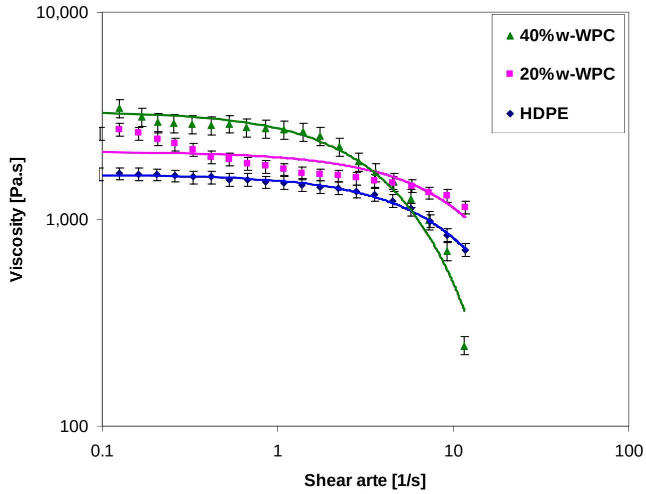

Figure 9 Viscosity of different WPC samples at 180°C

Using a capillary to make a pressure drop at known temperature in extrusion process, volume flow rate shall be calculated in compressible fluid flow through capillary [4, 6]. In gear pump dilatometry with same pressures at inlet and outlet of pump, the pump works as a measurement device for volume flow rate. By plotting data from above equation in $v-P$ and $v-T$ chart, PVT properties of WPCs will be achieved. For WPC melt the measurements of PVT are carried out. Some results are tabulated in Table 4 and PVT charts shown in Figures. 9 and 10. From PVT charts of WPCs isothermal compressibility and isobaric volumetric expansion coefficients shall achieved.

Table 4 Measured density of WPC melt at 40 bars

Temperature [C]	160	180	200
20%w-WPC	0.87±0.05	0.79±0.06	0.74±0.06
40%w-WPC	0.86±0.07	0.81±0.1	0.80±0.1

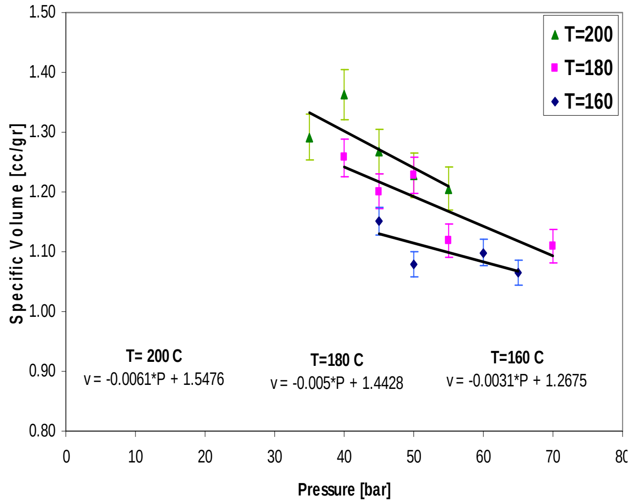

Figure 9 $v-P$ chart for 20% w-WPC

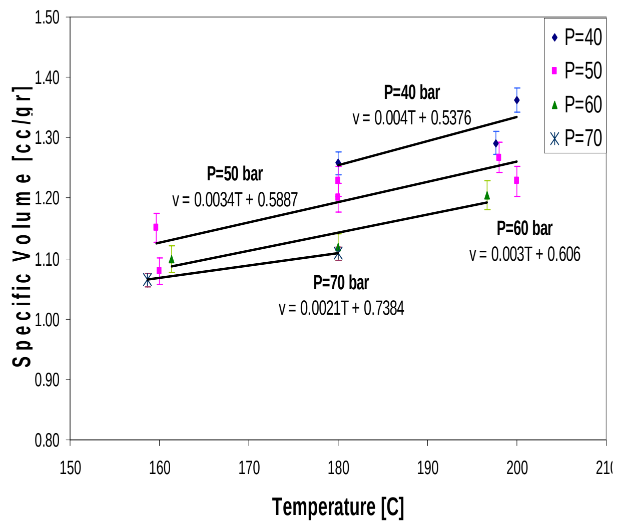

Figure 10 $v-T$ chart for 20% w-WPC

The results of solid state density investigations regarding the 40 % wood plastic experimentally is 1.06 gr/cm^3, and from rule of mixture is 1.09 gr/cm^3. Due to measuring solid state density of WPC, there is a good agreement between theoretical relation and measurements in presence of pressure.

5. Conclusions

In this paper an on-line method to measure the PVT properties of thermoplastic composite is introduced. The method based on the measurement of mass and flow arte of composite flow. The method is carried out for WPC as a new engineering material. The results are presented graphically and can be used for tool design and manufacturing process of WPC.

Acknowledgments

The authors would like to thank Tarbiat Modares University research affairs for the financial support. The Authors would like to thank Dr. A. H. Behravesh for his fruitful cooperation. Especial thanks to Mr. A. Pashaee and Mr. M. Poorzienelabedeen for their help in experiments.

List of Symbols

A	Coefficient
B	Coefficient
g	Gravity acceleration [m/s^2]
$K(P,T)$	Isothermal compressibility [1/bar]
K	Power law parameter
$\dot{m}$	Mass flow rate [gr/s]
n	Power law index
Q	Volume flow rate [cm^3/s]
R	Coefficient
r	Radius [cm]
S	Surface area [cm^2]
T	Temperature [C]
V	Velocity [m/s]
$v(0,T)$	Volume at zero pressure [cm^3]

v	Specific volume [cm^3/gr]
v_f	Fiber volume fraction
Z	Height [m]
$\beta(0,T)$	Volumetric expansion at zero pressure [1/C]
$\beta(P,T)$	isobaric volumetric expansion [1/C]
ΔP	Pressure drop [MPa]
$\dot{\gamma}$	Shear rate [1/s]
π	Pi number [3.141]
ρ_C	Composite density [gr/cm^3]
ρ_f	Fiber density [gr/cm^3]
ρ_m	Matrix density [gr/cm^3]
τ	Shear stress [Pa]
τ_Y	Zero shear rate stress [Pa]

References

[1] C. Clemons, “Wood-plastic composites in the united states, the interfacing of two industries”, Journal of Forest products, 2002.

[2] Y. Sato, H. Hashiguchi, S. Takishima, H. Masuoka, “Prediction of PVT properties of polymer melts with a new group contribution equation of state”, Fluid Phase Equilibria, 144, 427-440, 1998

[3] ASTM E 228-85: Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer, 1985

[4] N. Sadeghian, “Design and experimentation of PVT measurement system for Wood- Plastic Composites”, *MSc. Thesis*, Tarbiat Modares University, Tehran, 2007.

[5] Park S.S., Park C.B., ”On-Line Measurement of the PVT Properties of Polymer/CO_2 Solutions Using a Gear Pump”, Master of Science thesis, University of Toronto, 1999.

[6] Crawford R.J., “*Plastic Engineering*”, third edition, Butterworth Heinemann, 2002.

7] Shenoy, A.V., “*Rheology of Filled Polymer Systems”,* First edition, Kluwer Academic Publishers, 1999.

8] Ostwald, W., “Ueber die Viskositat Kolloider hosungen in Struktur-Laminar und Turbulezgebiet”, *Kolloid-Z.,* **38,** 261-280, 1926.

9] Advani S., “Flow and Rheology in polymer composites Manufacturing”, First Edition, Elsevier, 1994.

10] Hristov V., Takács E., and Vlachopoulos J., "Viscoelastic Behavior of Highly filled HDPE/Wood Flour Composites", ANTEC2005, pp. 1331-1335.