Journal of Engineering Physics and Thermophysics, Vol. 79, No. 4, 2006

DENSITY OF THE CONCENTRATES OF PEACH AND POME GRANATE JUICES AT ELEVATED STATE PARAMETERS

M. A. Magerramov

UDC 536.71:536.22:522.14

Investigation of the density of pomegranate and peach juices in the temperature range from 278.15 to 403.15 K at pressures of 0.1 and 5 MPa is carried out. The dependence of the density of the juices on the content of dry substances in them has been studied. The equations of state are written down and the coefficients of thermal expansion are calculated.

At the present time, the food industry is undergoing an intensive development. The value of the final product depends on the methods of its processing, storage, packing, and transportation [1–4]. At each of these stages, one must have available reliable information on various parameters of the object. Thermophysical properties occupy the most important place among this set of parameters. A change in the thermophysical properties of products may serve as an indicator of their quality. The data on various thermal, migratory, and electrophysical properties are used in designing processes and apparatuses used in industrial production. There is information in the literature on certain properties of a number of products obtained by processing fruits (in particular, [5–13]). However, an analysis of the available data points to a complete lack of any thermal characteristics of pomegranate juice, which possesses a wide range of biologically active substances and high organoleptic merits, allowing it to be put also to dietetic and medicinal-prophylactic uses. The favorable natural and climatic conditions in Azerbaijan offer vast possibilities of growing various sorts of pomegranates (more than 20) [14, 15]. The aim of the present work is to investigate the most important thermophysical property of the liquid substance, that is, its density.

The main task was to determine the temperature dependence of a natural pomegranate juice as well as its dependence on the content of dry substances. It is evident that within the framework of one research work one cannot cover of the initial product — pomegranate. In the present work, attention was focused on one sort — Iridana — as being the most attractive for processing, containing a large amount of juice (on average 48–54%) and tasting sweet and sharp.

Among the great variety of fruit juices, the peach one also occupies a rather important place, since biologically it is a very valuable fruit.

To carry out investigations, the fruits used were picked at the stage of biological ripeness. The juice produced mechanically was subjected to a chemical analysis. For pomegranate, the average values of the parameters were as follows: dry substances 17%, glucose 60 g/liter, fructose 70 g/liter, citric acid 10 g/liter, potassium 1100 mg/liter, chlorides 500 mg/liter, phosphates 300 mg/liter, and other mineral substances less than 50 mg/l iter.

To carry out investigations of the density, juice samples were kept for 2–3 h in glass containers in a darkened cool place. Samplings were made from the upper transparent settled layers of the juice. To obtain samples of juice of different concentrations of dry substance, the natural juice was subjected to vaporization in a vacuum apparatus at a temperature not exceeding 50^{o}C.

The density was measured on an experimental setup assembled for investigating fruit juices and based on the method of hydrostatic weighing. The basic principles for designing the structural units of the setup were borrowed from [16–19].

The main units of the setup are a measuring vessel which is filled with an experimental material and an air thermostat with double insulation as well as the systems of weighing, electronic tracking, creation and measurement of

Azerbaijan State Economical University, 6 Istiglaliyat Str., Baku, Az 1001, Azerbaijan. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 79, No. 4, pp. 174–178, July–August, 2006. Original article submitted April 28, 2005; revision submitted May 18, 2005.

TABLE 1. Density of the Natural Pomegranate Juice and of Its Concentrates at Elevated Parameters of State

T, K	c, %					
	17		23		40	
	0.1 MPa	5 MPa	0.1 MPa	5 MPa	0.1 MPa	5 MPa
278.15	1.0690	1.0712	1.1080	1.1102	1.2035	1.2058
293.15	1.0640	1.0663	1.1020	1.1044	1.1963	1.1989
303.15	1.0605	1.0628	1.0974	1.0997	1.1912	1.1936
313.15	1.0561	1.0585	1.0925	1.0948	1.1856	1.1879
323.15	1.0513	1.0537	1.0876	1.0900	1.1797	1.1824
333.15	1.0462	1.0486	1.0820	1.0843	1.1732	1.1755
343.15	1.0403	1.0427	1.0757	1.0781	1.1667	1.1690
353.15	1.0340	1.0365	1.0694	1.0718	1.1595	1.1622
363.15	1.0272	1.0298	1.0623	1.0647	1.1520	1.1548
373.15	—	1.0223	—	1.0572	—	1.1466
383.15	—	1.0143	—	1.0493	—	1.1374
393.15	—	1.0062	—	1.0409	—	1.1299
403.15	—	0.9976	—	1.0325	—	1.1212

TABLE 2. Density of the Natural Pomegranate Juice Concentrates at Atmospheric Pressure

T, K	c, %				
	44	50	55	60	65
278.15	1.2265	1.2572	1.2852	1.3140	1.3402
293.15	1.2181	1.2500	1.2770	1.3040	1.3300
303.15	1.2124	1.2445	1.2712	1.2980	1.3238
313.15	1.2064	1.2390	1.2652	1.2913	1.3170
323.15	1.2001	1.2324	1.2584	1.2840	1.3100
333.15	1.1934	1.2260	1.252	1.2778	1.3034
343.15	1.1862	1.2190	1.2445	1.2701	1.2964
353.15	1.1787	1.2118	1.2375	1.2632	1.2895
363.15	1.1711	1.2037	1.2298	1.2560	1.2830

pressure and temperature, and those of evacuation and filling. The thermostat had an internal heater and a system of air circulation. In the measurements, attention was especially paid to creation of a uniform temperature field in the measuring device. To control the uniformity of the temperature field over the height at different levels, several differential thermocouples were attached to the measuring device. The temperature of the experiment was measured by a PTS-10 resistance thermometer. The pressure in the system was determined with the aid of an MP-60 dead-weight pressure-gauge tester.

The computational equation used has the form

$$\rho = \frac{m - (m_2 - m_1)}{V_{\text{fl}}\Delta_1\Delta_2 + V_{\text{c}} + V_{\text{f}}}, \tag{1}$$

where $\Delta_1 = 1 + 3\alpha t$, $\Delta_2 = 1 - \psi P$, $\alpha = 0.43\cdot10^{-6}$ K^{-1}, and $\psi = 2.7\cdot10^{-6}$ cm^2/(kg·sec) are the coefficients of thermal expansion and compressibility of a quartz float.

In the method of hydrostatic weighing, the main measured quantity is the weight of the coil with a suspended system (m_2) and without it (m_1), with the remaining quantities in (1) being found by calibration. In determining the parameters of the suspended system, water was used as a standard liquid. The error of the measured quantities was

TABLE 3. Density of the Natural Peach Juice (14.5%) at Different Temperatures and Pressures

T, K	P, MPa		
	0.1	3	5
283.15	1.0651	1.0660	1.0667
298.15	1.0604	1.0611	1.0618
303.15	1.0585	1.0598	1.0606
308.15	1.0565	1.0578	1.0588
313.15	1.0544	1.0557	1.0567
318.15	1.0522	1.0535	1.0544
323.15	1.0498	1.0511	1.0521
328.15	1.0474	1.0488	1.0498
333.15	1.0448	1.0461	1.0471
338.15	1.0420	1.0435	1.0436
343.15	1.0391	1.0404	1.0415
348.15	1.0362	1.0377	1.0388
353.15	1.0331	1.0345	1.0356
363.15	1.0265	1.0280	1.0292
373.15	—	1.0205	1.0217
383.15	—	1.0129	1.0140
393.15	—	1.0050	1.0062
403.15	—	0.9967	0.9979

TABLE 4. Density of the Peach Juice Concentrates at Atmospheric Pressure and Different Content of Dry Substance

T, K	c, %									
	20	25	30	35	40	45	50	55	60	70
283.1	1.0915	1.1142	1.1380	1.1620	1.1868	1.2120	1.2365	1.2650	1.2945	1.3510
288.1	1.0900	1.1130	1.1365	1.1608	1.1854	1.2103	1.2348	1.2630	1.2925	1.3495
293.1	1.0885	1.1115	1.1352	1.1590	1.1837	1.2088	1.2328	1.2608	1.2908	1.3478
298.1	1.0868	1.1101	1.1335	1.1578	1.1820	1.2065	1.2310	1.2584	1.2890	1.3460
303.1	1.0850	1.1080	1.1318	1.1558	1.1802	1.2050	1.2292	1.2559	1.2871	1.3440
313.1	1.0810	1.1040	1.1277	1.1516	1.1763	1.2012	1.2253	1.2516	1.2833	1.3405
323.1	1.0764	1.0993	1.1235	1.1475	1.1719	1.1966	1.2210	1.2476	1.2791	1.3369
333.1	1.0715	1.0942	1.1186	1.1425	1.1670	1.1919	1.2163	1.2426	1.2745	1.3330
343.1	1.0661	1.0888	1.1132	1.1372	1.1619	1.1867	1.2115	1.2388	1.2697	1.3291
353.1	1.0600	1.0837	1.1073	1.1312	1.1560	1.1810	1.2060	1.2339	1.2645	1.3251
363.1	1.0535	1.0772	1.1010	1.1252	1.1500	1.1750	1.2005	1.2300	1.2590	1.3210

estimated on the basis of the computational equation with allowance for the recommendations known. The calculations showed that for the density in the temperature interval up to 420 K it does not exceed $\pm 0.06\%$.

Table 1 presents the results of determination of the natural pomegranate juice density with a content of dry substances of 17%, as well as of its two concentrates (23 and 40%) in the temperature interval 278.15–403.15 K at pressures of 0.1 and 5 MPa. The results of measurements of the density of the pomegranate concentrates (with a dry substance content of 44, 50, 55, 60, and 65%) at atmospheric pressure are presented in Table 2. The experimental data on the density of a natural peach juice at elevated parameters of state as well as its concentrates (20, 25, 30, 35, 40, 45, 50, 55, 60, and 70%) are presented in Tables 3 and 4, respectively.

In the literature, there are data on the thermophysical properties of peach juice at atmospheric pressure [9, 10, 13]. In [9], investigation of the density of some fruit juices is carried out, but the data have not been tabulated. Only

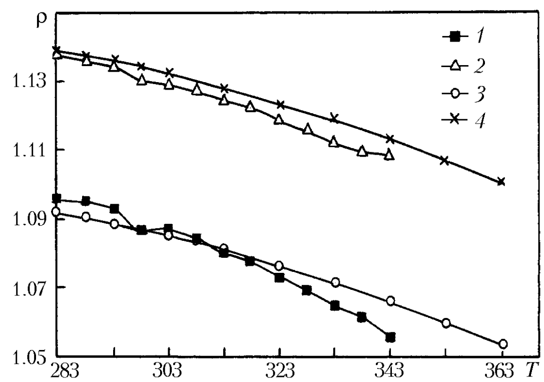

Fig. 1. Comparison of the literature [10] values of the peach juice density (1, 2) with the results of the present work (3, 4) at dry substance content of: 1, 3) 20%; 2, 4) 30%.

TABLE 5. Values of the Empirical Coefficients of the Equation of State of Pomegranate and Peach Juices

i	$j = 0$	$j = 1$	$j = 2$
Pomegranate Juice			
0	0.9676	$-1.6873 \cdot 10^{-4}$	$-1.9842 \cdot 10^{-6}$
1	$6.2118 \cdot 10^{-3}$	$-4.2213 \cdot 10^{-6}$	$-4.8493 \cdot 10^{-8}$
2	$-6.7477 \cdot 10^{-6}$	$-4.7787 \cdot 10^{-8}$	$1.1393 \cdot 10^{-9}$
Peach Juice			
0	1.0084	$3.9519 \cdot 10^{-3}$	$1.4143 \cdot 10^{-5}$
1	$-2.3285 \cdot 10^{-4}$	$1.0661 \cdot 10^{-6}$	$-3.5636 \cdot 10^{-8}$
2	$-5.0979 \cdot 10^{-6}$	$1.8055 \cdot 10^{-7}$	$-2.3518 \cdot 10^{-9}$

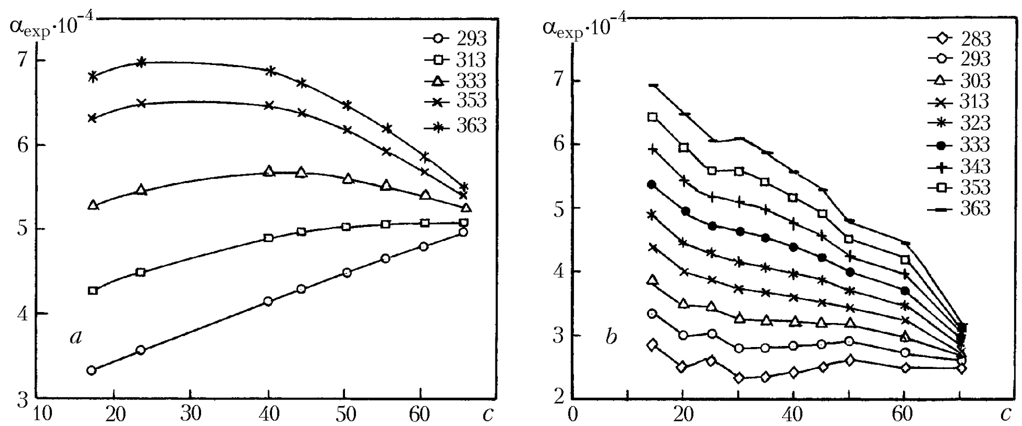

Fig. 2. Thermal coefficients of expansion vs. the dry substance concentration at different temperatures: a) pomegranate juice; b) peach juice.

an equation which describes the density as a function of the temperature and concentration of a dry substance is given. For peach juice, the confidence value of approximation by the equation (correlation factor) is equal to 0.993. For comparison purposes, according to our results, the correlation factor for Eq. (1) is equal to no less than 0.9999. At low temperatures (to 303 K) the agreement is rather satisfactory. At higher temperatures there is a discrepancy which increases with temperature. In [10], data on the density at 5–70°C and on the content of a dry substance (10–16%) are given, but their error is not indicated. A comparison of our data with the results of that work is given in Fig. 1. Their satisfactory agreement is observed.

Based on the data obtained, an equation was composed which describes the dependence of the density on temperature and on the content of a dry substance. Preliminary calculations have shown that a satisfactory accuracy can be attained by using a second-order polynomial for describing both the temperature and concentration dependences. When expanded, the equation has the form

$$\rho = a_{00} + a_{10}c + a_{20}c^2 + a_{01}t + a_{11}ct + a_{21}c^2t + a_{02}t^2 + a_{12}ct^2 + a_{22}c^2t^2 ,$$

where $t = T - 273.15$. The values of the coefficients a_{ij} are presented in Table 5.

Having the equation of state, it is possible to determine the coefficients of thermal expansion. Figure 2 shows the change in the quantity α_{exp} depending on the dry substance concentration. It is interesting that according to the data of our investigation the change in α_{exp} with the pomegranate juice concentration is greatly dependent on temperature. At temperatures above room temperatures, one maximum has been detected. Depending on temperature, the value of α_{exp} increases, just as for the majority of liquids.

Thus, based on the comparison of the coefficients of thermal expansion of the substances under study, different influences of the parameters of state on their volumetric properties have been established. In peach juice, α_{exp} practically monotonically decreases with an increase in the concentration. In pomegranate juice, at room temperature an increase in the value of α_{exp} is observed, whereas at high temperatures the value of α_{exp} decreases.

NOTATION

a_{ij}, empirical coefficients; c, content of a dry substance, %; m, mass of a suspended system in vacuo, g; m_2 and m_1, masses of weighed main coil with a suspended system and without it, g; P, pressure, MPa; T, temperature, K; K_{fl}, V_c, and V_f, volume of the float, core, and filament, respectively, cm^3; α_{exp}, coefficient of thermal expansion, K^{-1}; α, coefficients of thermal expansion of the quartz float, K^{-1}; ρ, density, g/cm^3; ψ, compressibility of the quartz float, cm^2/(kg·sec). Subscripts: fl, float; c, core; f, filament; exp, expansion.

REFERENCES

1. A. Perez-Vicente, P. Serrano, P. Abellan, and C. Garcia-Viguera, Influence of packaging material on pomegranate juice colour and bioactive compounds, during storage, *J. Sci. Food Agric.*, **84**, 639–644 (2004).
2. N. Marti, A. Perez-Vicente, and C. Garcia-Viguera, Influence of storage temperature and ascorbic acid addition on pomegranate juice, *J. Sci. Food Agric.*, **82**, 217–221 (2001).
3. S. A. Al-Maiman and D. Ahmad, Compositional changes in physical and chemical properties during pomegranate (*Punica granatum L.*) fruit maturation, *Food Chem.*, **76**, No. 4, 437–441 (2002).
4. S. Velioglu, C. Unal, and B. Cemeroglu, Chemical characterization of pomegranate juice, *Fruit Process.*, No. 8, 307–310 (1997).
5. A. S. Ginszburg, M. A. Gromov, and G. I. Krasovskaya, *Thermophysical Properties of Food Products* [in Russian], Pishchevaya Promyslennost', Moscow (1980).
6. B. R. Gochiyaev, Determination of viscosity and specific weight of apple juice, *Izv. Vyssh. Uchebn. Zaved., Pishch. Tekhnol.*, No. 4, 93–95 (1964).
7. V. A. Maslikov and O. K. Medvedev, Some thermophysical constants of tomato products, *Izv. Vyssh. Uchebn. Zaved., Pishch. Tekhnol.*, No. 6, 69–70 (1969).
8. V. A. Subbotin and V. P. Popov, Thermophysical properties of grape and products of its processing, *Tr. VNII Vinodel. Vinograd.*, **15**, 36–51 (1967).
9. J. D. Alvarado and C. H. Romero, Physical properties of fruits I-II. Density and viscosity of juices as a function of soluble solids content and temperature, *Latin American Appl. Res.*, **19**, 15–21 (1989).
10. A. M. Ramos and A. Ibars, Density of juice and fruit puree as a function of soluble solids content and temperature, *J. Food Eng.*, **35**, 57–63 (1998).
11. L. Bayindirli, Mathematical analysis of variation of the density and viscosity of apple juice with temperature and concentration, *J. Food Process. Preserv.*, **16**, 23–28 (1992).

12. G. D. Saravacos and A. E. Kostaropoulos, Transport properties in processing of fruits and vegetables, *Food Technol.*, No. 9, 99–105 (1995).
13. A. Ibars, Rheology of clarified fruit juices. I. Peach juices, *J. Food Eng.*, **15**, 49–61 (1992).
14. M. A. Magerramov, *Storage of Pomegranate Fruits in a Modified Gaseous Medium*, Candidate Thesis (in Eng.), OTIPP, Odessa (1990).
15. M. A. Magerramov, *Properties of Pomegranate Fruits and Their Storage in Modified Atmosphere* [in Russian], AASU, Baku (2002).
16. I. F. Golubev, Determination of specific weight of liquids and gases at high pressures by the method of hydrostatic weighing, *Tr. GIAP* (Moscow), Issue 7, 47–57, (1957).
17. A. K. Abas-zade, A. M. Kerimov, N. A. Agaev, and T. A. Apaev, Experimental determination of the density of hydrocarbons, in: *Thermophysical Properties of Liquids* [in Russian], Nauka, Moscow (1970), pp. 34–38.
18. B. V. Voityuk, V. A. Rabinovich, L. V. Moseichuk, and A. A. Denisenko, A sample setup for studying P-, V-, and T-dependences of liquids by the method of hydrostatic weighing, in: *Thermophysical Properties of Substances and Materials* [in Russian], Issue 8, GSSSD, Moscow (1974).
19. K. D. Guseinov, *Study of Thermodynamic and Transport Processes of a Number of Oxygen-Containing Organic Substances within a Wide Range of State Parameters*, Doctoral Thesis (in Eng.), AzNKhI, Baku (1979).