Transient Temperature Variations in Pressure Fluids Due to Changes in Pressure

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USE OF HYDROSTATIC PRESSURE as a variable for different studies is hampered by the change in temperature which takes place as the pressure fluid is compressed or expanded. In most high pressure tests, the work of compressing the fluid causes a temperature change depending on the pressure fluid, time for pressure to change, and the pressure vessel. It is possible to calculate this temperature change for most fluids, (5) but the number of variables which can affect the calculation makes the calculated values only a rough guess. This report covers eight different liquid pressure fluids and one gas (helium), along with three different pressure systems and vessels. Curves showing the maximum temperature increase due to compression of the fluid and the time to return to room temperature are given for all the fluids. The effect of the various pressure systems and pressure vessels is discussed.

Except for helium, the compression and expansion of the test fluid may usually be carried out fairly rapidly in comparison with the time for appreciable flow of heat into or out of the pressure vessels. The measured temperature changes are compared with values calculated assuming adiabatic conditions.

PRESSURE SYSTEMS

The 20,000-p.s.i. system (Figure 1,*A*) consists of a 40,000-p.s.i.g. Blackhawk hand pump (Model p-228) and a 20,000-p.s.i.g. Heise gage. The vessel being used is connected to the system using high pressure connectors. Certain liquids (alcohol, water, and acetone) would not pump with the hand pump. In these cases the vessel and high-pressure tubing were filled with the fluid under test, and hydraulic oil was used in the hand pump. At the end of the test there would be a slight amount of oil (probably less than 3%) in with the fluid under test. The simplicity of the pressure system made changing of pressure fluids a quick and easy operation.

Pressures up to 50,000 p.s.i.g. were obtained with a conventional pressure system (Figure 1,*B*) using a hand pump and intensifier to compress the pressure fluid. This system may require recharging the intensifier during a pressure stroke, and the time to compress the fluids is longer than with the 20,000-p.s.i. system.

The gas system used for the 2000- and 20,000-p.s.i.g. helium readings consists of a mercury gas compressor and an air-driven pump which pumps oil to compress the gas through the mercury piston (Figure 1,*C*).

The temperature was measured using a copper-constantan thermocouple with one junction in the center of the pressure vessel and the other in ice water. The output was read on a digital voltmeter.

RESULTS

Eight different liquid pressure media were used in the 20,000-p.s.i. system. The pressure was pumped by hand to 20,000 p.s.i.g. in approximately 30 to 60 seconds. The temperature was recorded while maintaining 20,000 p.s.i.g. until the pressure fluid returned to room temperature, approximately 23° C. (within 1°). The pressure was then decreased to atmospheric pressure (in about 5 seconds) and the decrease in temperature recorded along with its return to room temperature. Figure 2 shows a plot of the

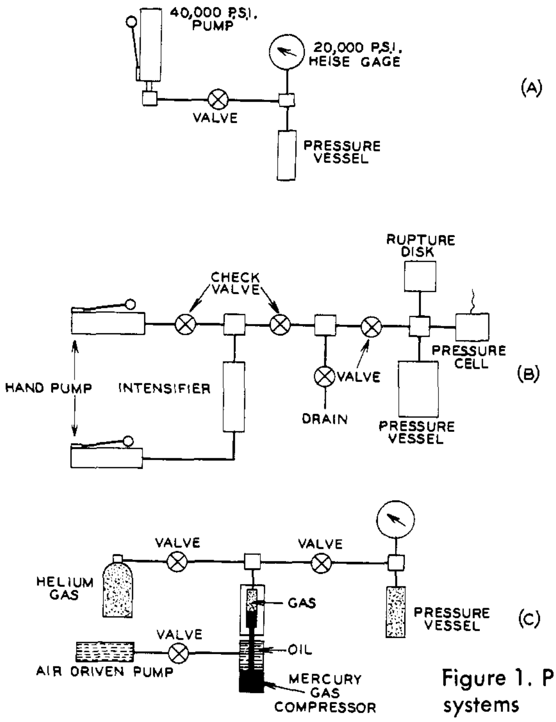

Figure 1. Pressure systems

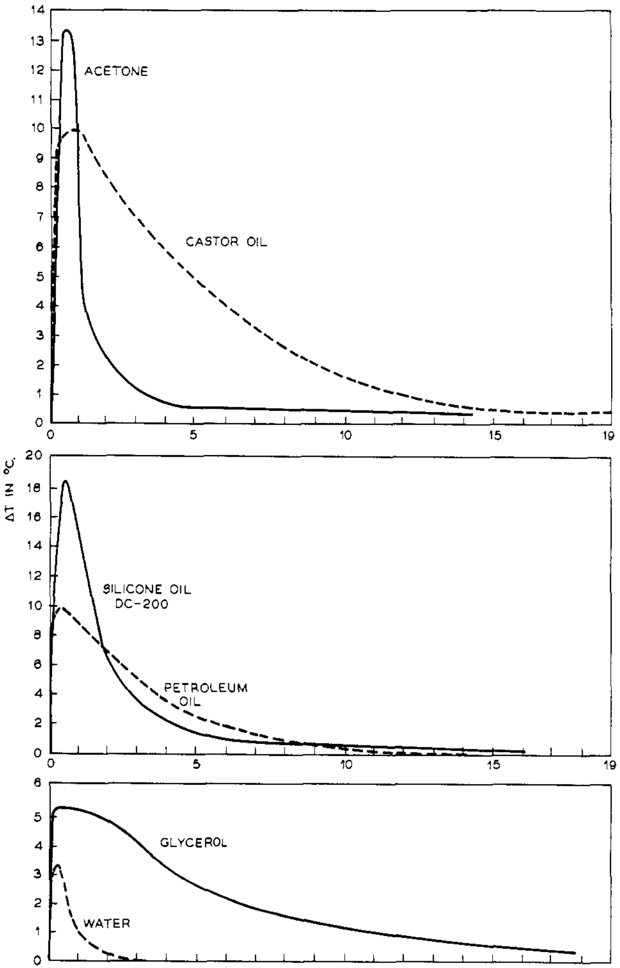

Figure 2. Temperature change vs. time while pressure is increased from atmospheric to 20,000 p.s.i. and held there (vessel *B* of Figure 4)

temperature change resulting from a 20,000-p.s.i.g. pressure increase *vs.* time for each pressure fluid used. The time to return to room temperature was about the same for an increase or decrease in temperature. Table I shows the temperature rise upon pumping up to 20,000 p.s.i.g., the temperature drop upon release of the pressure, and the time to return to room temperature while at 20,000 p.s.i.g. There is a different temperature change for increasing and decreasing the pressure partly because of the time required to pump the pressure to 20,000 p.s.i.g. and partly the effect of temperature on the properties of the pressure fluid. Table I also shows the calculated values of the temperature change if the system were completely adiabatic, while Table II gives the values of the fluid properties used in the calculations. As expected, the calculated temperature changes are somewhat larger than the measured values.

The temperature variation due to different pressures is shown in Figure 3. Alcohol was tested at 10,000 and 20,000 p.s.i.g. using the pressure system in Figure 1,*A*. Kerosine was tested in three different vessels at several pressures ranging from 10,000 to 50,000 p.s.i. using the intensifier pressure system in Figure 1,*B*. The results are shown in Table III and Figure 4. As can be seen from Figure 4, the material and geometry of the pressure vessel affected primarily the time to return to room temperature, rather than the maximum temperature excursion.

Vessels *A* and *C*, (Figure 4), are made of 316 stainless steel and can be used for materials or tests which would affect regular steel. Vessel *B* is made of heat-treated ketos steel (a fine grain tool steel) which is easy to machine and makes a good general vessel for use with oil or kerosine. The pressure vessels use a standard seal described by Bridgman (*1*).

Table I. Temperature Changes Due to Change in Pressure

	ΔT, ° C.			
	1 atm. to 20,000 p.s.i.	20,000 p.s.i.g.	Calcd. Values, ° C.	Time[a]
Acetone	13.3	20.5	34.5	3
Alcohol	10.3	14.7	23.6	2
Castor oil	9.9	9.8	. . .	11
Glycerol	5.3	5.3	6.8	12
Kerosine	14.0	14.3	. . .	8
Petroleum oil	9.8	9.8	21.7	7.5
DC 200 silicone oil	18.6	18.6	. . .	7
Water	3.3	3.25	3.34	1.5
Helium (g)	. . .	94.8° C.	280	4

[a] Time for return to room temperature within 1°, min.

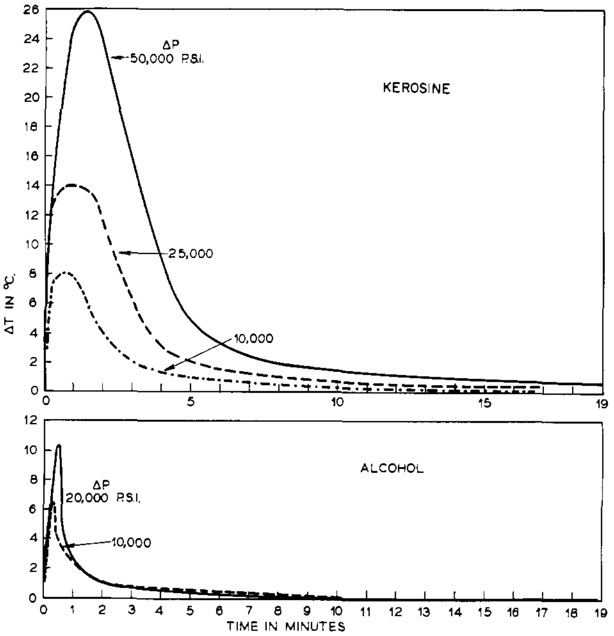

Figure 3. Temperature change vs. time while pressure is increased from atmospheric to various pressures as indicated (kerosine, vessel C; alcohol, vessel *B*)

The time required to compress helium gas to 2000 or 20,000 p.s.i.g. is long; therefore, the temperature change shown in Figure 5 for helium was obtained when the gas was released from 2000 or 20,000 p.s.i.g. down to atmospheric pressure. The temperature change as the gas was compressed is shown by the bottom curve of Figure 5.

TEMPERATURE CHANGE IN REVERSIBLE ADIABATIC CHANGE OF PRESSURE

The formula for $(\partial T/\partial p)_S$ is shown below (*6*):

$$\left(\frac{\partial T}{\partial p}\right)_S = \left(\frac{\partial T}{\partial V}\right)_S \left(\frac{\partial T}{\partial p}\right)_S = \frac{TV\beta\chi_S}{C_V\chi_T} = \frac{T\beta}{\rho C_p} \qquad (1)$$

where the last form results from the substitutions $V = 1/\rho$ and $\chi_S/\chi_T = C_V/C_p$.

A rough calculation which considers the internal energy to depend only on the temperature gives the wrong impression that the observed temperature changes are anomalously large. Such a calculation results in the formulas

$$\left(\frac{\partial T}{\partial V}\right)_S \approx -\frac{p}{C_V} \text{ and } \left(\frac{\partial T}{\partial p}\right)_S \approx \frac{p\chi_S}{\rho C_V} \qquad (2)$$

Table II. Average Values of Parameters Used in Calculation (*1–4*)

($T = 296°$ K., $p = 10{,}000$ p.s.i.g.)

Fluid	$\bar{\rho}$, G./Ml.	$\bar{\beta}$ (° K.)$^{-1}$	$\bar{C}_p$,[a] Cal./G. per ° C.	$\bar{\chi}_T$, Sq. cm./Dyne	$(\partial T/\partial p)_S$,[b] ° K./(P.S.I.G.)	$(T\beta/p\chi_T - 1)$. Dimensionless
Acetone	0.792	0.00148	0.528	12.75×10^{-11} 20° C. 1 atm.	1.72×10^{-3}	3.97
Methanol	0.810	0.001199	0.602	10.27×10^{-11} 14.7° C. 37 atm.	1.18×10^{-3}	4.01
Glycerol	1.260	0.000505	0.576	2.48×10^{-11} 20.5° C.	3.42×10^{-4}	7.76
Kerosine	0.800	. . .	0.500	. . .	. . .	. . .
Petroleum oil	0.8467	0.000955	0.511	6.87×10^{-11} 1.65° C.	1.085×10^{-3}	5.14
Water	1.02	0.000333	0.95	4.58×10^{-11} 20° C. 1 atm.	1.67×10^{-4}	2.03

[a] Tabulated values of C_p were multiplied by 4.186×10^7 ergs/cal. to convert to ergs/g. per ° C. [b] 1 p.s.i.g. = 6.895×10^4 dynes/sq. cm.

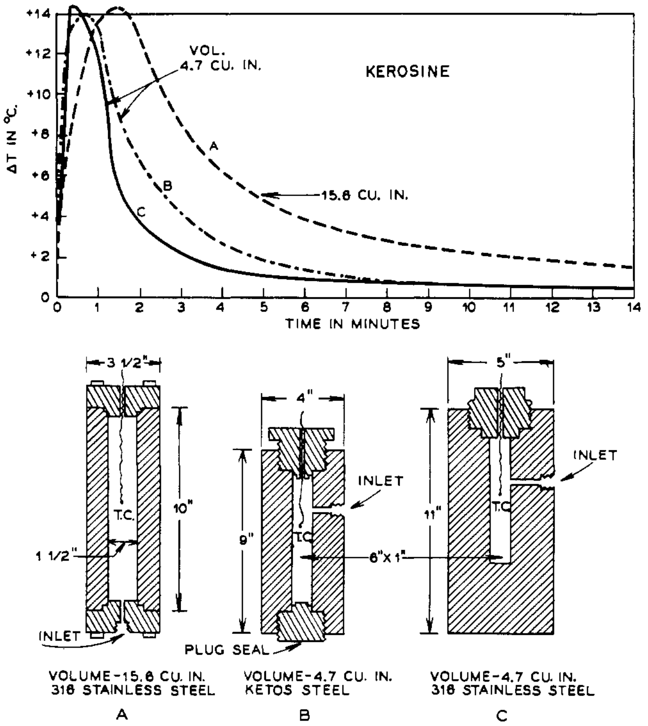

Figure 4. Temperature change vs. time for an increase in pressure from atmospheric to 20,000 p.s.i.

The error in this rough calculation, expressed as a fraction of the rough value, is

$$\left(\frac{T\beta}{\rho C_p} - \frac{p\chi_S}{\rho C_V}\right) \Big/ \left(\frac{p\chi_S}{\rho C_V}\right) = \left(\frac{T\beta}{p\chi_T} - 1\right) \qquad (3)$$

Values of $(T\beta/p\chi_T - 1)$ for several pressure media are shown in Table II. For many of these fluids, the rough calculation is so rough that it is actually misleading. For these fluids, it is not permissible to regard the internal energy as a function only of the temperature.

The calculated adiabatic temperature changes for the liquids were obtained from the formula

$$\Delta T = \frac{T\beta}{\rho C_p}(p_f - p_i) \qquad (4)$$

using the average values of fluid properties shown in Table II. For helium, the perfect gas calculation with $\gamma = 1.66$ was used:

$$\frac{T}{T_0} = \left(\frac{p}{p_0}\right)^{\frac{\gamma - 1}{\gamma}} \qquad (5)$$

The proper average value of expansion coefficient is felt to be the least reliable of the values entering the calculations. This factor may undergo relatively large percentage variations with pressure as well as temperature.

In all cases, there are some nonadiabatic effects owing to the finite heat capacity and thermal conductivity of the thermocouple, as well as to heat exchange with the vessel walls. These effects are more marked for helium than the liquids because of its larger temperature excursion and smaller heat capacity per unit volume.

NOMENCLATURE

C_p = specific heat at constant pressure
C_v = specific heat at constant volume
p = pressure
S = entropy
T = temperature
V = volume
β = $(1/V)(\partial V/\partial T)_p$ = volume expansivity
ρ = $1/V$ = density
χ_S = $-(1/V)(\partial V/\partial T)_s$ = isentropic (adiabatic) compressibility
χ_T = $-(1/V)(\partial V/\partial T)_T$ = isothermal compressibility

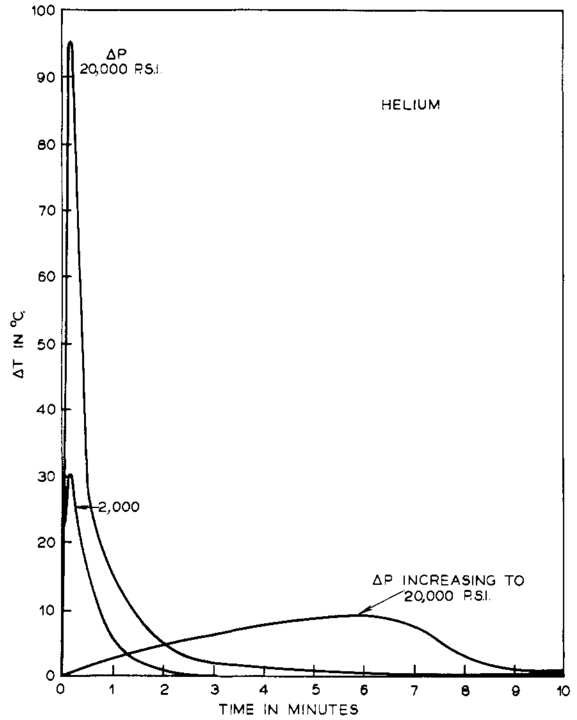

Figure 5. Temperature change vs. time, for a decrease in pressure of 2000 and 20,000 p.s.i. (vessel C)

Table III. Temperature Changes Due to Change in Pressure for Kerosine

Pressure Change, P.S.I.	Pressure Change Time, Sec.	ΔT from 23° C.	Vessel (Figure 4)
Atm. to 10,000	15	8.2	*C*
10,000 to atm.	0.5	7.3	*C*
Atm. to20,000	60	14.1	*A*
20,000 to atm.	2	14.0	*A*
Atm. to 20,000	15	14.0	*B*
20,000 to atm.	1	14.3	*B*
Atm. to 20,000	15	13.7	*C*
20,000 to atm.	1	13.9	*C*
Atm.to 25,000	30	13.9	*C*
25,000 to atm.	1	15.7	*C*
Atm. to 10,000	30	7.6	*B*
10,000 to 30,000	30	12.7	*B*
30,000 to atm.	2	19.6	*B*
Atm. to 42,000	105	20.6	*B*
40,000 to atm.	2	26.2	*B*
Atm. to 50,000	90	25.9	*C*
50,000 to atm.	3	28.0	*C*
Atm. to 50,000	165	22.5	*C*
50,000 to atm.	2	28.0	*C*

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RECEIVED for review July 7, 1961. Accepted December 1, 1961.