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Laboratory Note

Joule-Thompson Coefficient for Anesthetic Gases

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The Joule-Thompson coefficient, which relates change of temperature to change of pressure, was calculated for several gaseous and volatile anesthetic agents from heat capacity, critical temperature, and critical pressure, using a computer program. It was found that agents such as nitrous oxide and carbon dioxide which have high constant tank pressures as well as large Joule-Thompson coefficients and high condensation points may cause problems with valve freezing. (Key words: Joule-Thompson coefficient; van der Waal constant; Gas, expansion; Gas, cooling.)

THE JOULE-THOMPSON EFFECT is well known to anesthesiologists.[1] When a compressed gas escapes from a storage cylinder through a narrow valve orifice into the atmosphere, the gas cools during its passage through the valve. The gas passing through the orifice then cools the area of the cylinder in and around the valve, and moisture from the atmosphere may condense there. This effect is independent of the cooling of the upper part of a tank that results from the extraction of heat necessary to vaporize liquid to gas within the cylinder.

In the past, for example, great care was taken in the preparation of tanks of nitrous oxide to ensure that before compression the gas was free of water vapor. The cooling which takes place when a cylinder valve is "cracked" may be sufficient to freeze any admixed water vapor and block the valve. To prevent this, heat was supplied directly to the valve by a warm-water bath, spirit lamp, or warm towels. "Fins" were also added to reducing valves to facilitate heat transfer from the atmosphere in order to maintain the temperature within the valve above 0 C. With modern drying techniques, however, the frozen nitrous oxide exit valve is no longer a problem.

This phenomenon of the gaseous state, cooling due to expansion, is called the "Joule-Thompson effect," and occurs because of departure of real gases from the ideal gas laws. As a gas streams from an area of high pressure (storage cylinder) through a porous plug or throttle (reducing valve) to an area of low pressure (atmosphere, anesthesia circuit), the molecules disperse and external work is performed in overcoming the attraction the molecules have for each other. When this is an adiabatic process, internal energy is utilized and the temperature of the gas falls. An ideal gas will not cool on expansion because there is no attraction between the molecules. Anesthetic gases, however, are not ideal, and when expansion through a reducing valve occurs the diffusion of heat from the atmosphere to the gas is relatively slow and the process approaches the adiabatic state.

The Dutch physicist Johannes D. van der Waal (1873–1923) modified Boyle's law to describe the behavior of real gases that deviate moderately from ideality. He considered the volume the molecules themselves occupy, as well as the attraction they exert on each other, thus

$$(P + a/V^2)(V - b) = RT$$

where

a = attractive force between molecules (liter² atm/mole²)

b = actual volume occupied by molecules (liter/mole)

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P = observed pressure (atm)
R = gas constant (liter atm/K/mole)
T = observed temperature (K)
V = observed volume (liters).

The Joule-Thompson coefficient u, or dT/dP, (the ratio of temperature fall to pressure drop) is less well known to anesthesiologists. Values of u for common anesthetic agents are not available in standard texts of anesthesia or handbooks of physical constants.[2] Using classic equations of physical chemistry, a computer program was written to calculate u from readily available data.[3]

To calculate the Joule-Thompson coefficient it is necessary to know the heat capacity at constant pressure, C_p, or the number of calories needed to raise the temperature of 1 mole of gas 1 C; the critical temperature T_c, or the temperature above which a substance cannot exist in the liquid state, and the critical pressure P_c, or the pressure necessary to liquify a gas at its critical temperature. These values of C_p, T_c and P_c are readily available, as they are important constants for industry dealing with compressed gases.[3]

It can be shown[4] that

$$u = \frac{2\,a/RT - b}{C_p}$$

where

$$a = \frac{27\,R^2T_c^2}{64\,P_c}$$

$$b = \frac{RT_c}{8\,P_c}$$

and

C_p = heat capacity (cal/mole)
P_c = critical pressure (atm)
T = ambient temperature (20 C or 293 K)
T_c = critical temperature (K)
u = Joule-Thompson coefficient (K/atm)

Discussion

Since u = dT/dP, to calculate the decrease in temperature dT from Joule-Thompson expansion, u and dP must be known. The values for u have been calculated and are given in table 1. The driving pressure on pressure drop dP is tank or gauge pressure (see table 2). dP is constant for vapor above liquified gases such as nitrous oxide, carbon dioxide, and cyclopropane, since so long as some liquid remains in the cylinder gauge, pressure will remain constant. Thus, for nitrous oxide $51.0 \times 0.7165 = 36.5$ C, a drop in temperature certainly great enough to cause freezing of any water in a valve. This problem does not exist with cyclopropane even though it has a much greater Joule-Thompson coefficient than nitrous oxide because its tank pressure is much lower.

The condensation temperatures for the anesthetic agents present as gases in cylinders[3] are listed in table 3. As can be seen, the condensation point for cyclopropane is relatively high, but this is offset by the extremely low tank pressure. Hydrogen and helium have

TABLE 1. Values for a, b and u as Calculated from C_p, P_c and T_c

Gas	a	b	u
Air	1.3378	0.0366	0.2711
Carbon dioxide	3.6063	0.0424	0.7127
Chloroform	15.1141	0.1018	1.6915
Cyclopropane	8.3333	0.0756	1.1208
Diethyl ether	17.4523	0.1349	0.9864
Ethyl chloride	11.5600	0.0907	1.4430
Ethylene	4.4486	0.0568	0.7578
Halothane	23.5834	0.1497	1.1808
Helium	0.0353	0.0241	−0.1030
Hydrogen	0.2446	0.0266	−0.0224
Nitrogen	1.3667	0.0392	0.2597
Nitrous oxide	0.2446	0.0443	0.7165
Oxygen	1.3667	0.0316	0.2789
Trichloroethylene	16.9839	0.1127	0.9682
Water	5.4550	0.0304	1.2470
Xenon	4.1107	0.0512	1.3531

TABLE 2. Values for Gauge Tank Pressures of Full Tanks of Gaseous Anesthetics

Gas	Gauge Tank Pressure (atm)
Cyclopropane	6.3
Nitrous oxide	51.0
Ethylene	85.0
Helium	200.0
Carbon dioxide	56.0
Nitrogen	150.0
Oxygen	200.0
Atmospheric air	200.0
Ethyl chloride	0.3

TABLE 3. Condensation Points at One Atmosphere

Gas	Degrees C
Cyclopropane	−33
Nitrous oxide	−88
Ethylene	−104
Helium	−269
Carbon dioxide	−78
Nitrogen	−196
Oxygen	−183
Air	−194
Xenon	−108

negative Joule-Thompson coefficients, which means that these gases warm on expansion, as has been observed experimentally. It was found that agents such as nitrous oxide and carbon dioxide that have high constant tank pressures as well as large Joule-Thompson coefficients and high condensation points can give problems with valve freezing. With nitrous oxide this is compounded further by the fact that the freezing point is within two degrees of the condensation point.[5]

For gases such as oxygen and compressed air, gauge pressures fall as the amount of gas diminishes, and dP will become smaller as the tank is bled. Thus, cooling owing to Joule-Thompson expansion will decrease as the tank is bled. However, none of this cooling results in any observable change in gas flow because the condensation points for these gases are so low.

References

1. Adriani J: Chemistry of Anesthesia. First edition. Springfield, Ill., Charles C Thomas, 1946, pp 9–10
2. Secher O: Physical and Chemical Data on Anaesthetics. Acta Anaesthesiol Scand suppl XLII, 1971
3. Macintosh R, Mushin WW, Epstein HG: Physics for the Anaesthetist. Third edition. Philadelphia, F. A. Davis Company, 1963, pp 418–423
4. Glasstone S: Textbook of Physical Chemistry. Second edition. New York, D. Van Nostrand, 1946, pp 292–293
5. Braker W, Messman AL: Gas Data Book. Fifth edition. East Rutherford, New Jersey, Matheson Gas Co., 1971

Neonatology

MONITORING PERFUSION IN CARDIOPULMONARY BYPASS Two techniques are reported: 1) the use, in the neonate, of the umbilical artery rather than the aorta for extracorporeal circulation; 2) the use of a muscle *p*H electrode for continuous monitoring of muscle *p*H as an indicator of peripheral tissue perfusion and respiration. The umbilical artery is easier, faster, and simpler to use for extracorporeal circulation than the aorta and was adequate from the hemodynamic point of view: 300 ml/min at a perfusion pressure of 110 mm Hg with a no. 8 Fr. end-hole polyethylene feeding tube. Complications of umbilical-artery catheterization are discussed.

When perfusion is adequate, muscle *p*H is essentially the same as arterial *p*H. When muscle perfusion decreases, muscle *p*H falls due to lactic acid production but arterial *p*H will not reflect it, since inadequate perfusion does not remove the lactic acid from the muscle. This difference between muscle *p*H and arterial *p*H forms the basis for monitoring the inadequacy of peripheral perfusion. (*Harken, A. H., and Filler, R. M.: The Use of the Umbilical Artery and Muscle pH Monitoring in Neonatal Cardiopulmonary Bypass, J. Thorac. Cardiovasc. Surg. 63: 973–976, 1972.*)