TABLE 3

Flavor Evaluation of Continuously Deodorized Soybean Oil Extracted with Supercritical CO_2[a,b]

Storage at 60 C (days)	Deodorized Commercial Oil	CO_2 Extracted Crude			
		Celite-Filtered		No Treatment	
0	7.1	7.4	8.0	6.8	7.1
4	6.0	5.6	6.7	6.1	6.0

[a]Rating scale of 10: 1, strong; 10, bland.

[b]Deodorization conditions, see Table 2.

with SC-CO_2. Thus, steam deodorization of SC-CO_2 extracted crude soybean oil, without any prior refining, produces oil equivalent to commercially deodorized oils.

Laboratory continuous deodorizers of the type described here have several useful applications. They can be incorporated into a minirefinery (14) which more nearly simulates industrial practice, they serve as a means of testing transducers and sensors for computer control applications (15,16), and they can be used to produce research-sized samples for organoleptic evaluation of oils.

ACKNOWLEDGMENTS

Thanks go to our taste panel members and staff; our glass blower, F. Castle, and Gary List for oil processing before deodorization.

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Flow of Vegetable Oil-Pesticide Blank-Formulation Mixtures through Agricultural Spray Nozzles[1]

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Properties of specific gravity, viscosity and flow rate were measured for cottonseed and soybean oil mixed with selected blank pesticide formulations without the active ingredient, i.e., blank-formulations. Fluid temperature ranged from 5 to 70 C for the measurements. Specific gravity of soybean oil mixtures was found to vary approximately 5% inversely with temperature over the temperature range. Above 65 C the mixtures exhibited approximately the same viscosity. Cottonseed oil viscosity remained less than the soybean oil viscosity over the entire range of temperatures studied. Addition of blank-formulation materials resulted in more reduction in viscosity at lower temperatures. Flow rates were measured over the temperature range for selected mixtures through different sizes and types of hydraulic spray nozzles. Fitted equations were derived to predict the necessary pressure correction for temperature for each nozzle and mixtures tested.

The potential for reducing the diluent application rate while maintaining pesticide efficacy has resulted in widespread use of vegetable oils as a carrier. It is estimated that about 125 million l per yr of vegetable oil could be used on soybeans and cotton for insect control alone (1). Such large scale use and relatively rapid adaptation of vegetable oil as a diluent for use in equipment designed primarily for water has prompted the investigation reported in this paper.

EQUIPMENT AND PROCEDURE

The objective was to measure selected physical properties for several vegetable oil tank mixes that

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directly affect aerial application equipment and would tend to influence its performance. Properties measured included specific gravity, viscosity and flow rate over the expected operating temperature range of the mixtures in an aircraft tank. Table 1 lists the oils and mixtures evaluated. The Ambush® and Pounce® formulations were blank formulations; that is, they did not contain any pesticide active ingredient.

Specific gravity. The specific gravity of the mixtures corrected for temperature was determined with a fulcrum-balance device sensitive to 0.0001 g. The mixtures were placed in a constant temperature water bath and allowed to equilibrate prior to each reading.

Viscosity. Viscosity was measured with a Brookfield Viscometer Model RVT with a No. 1 spindle at 50 rpm. The viscometer was allowed one min to stabilize after the motor was started. Thermocouples placed in a mixture measured temperature at the time viscosity reading was taken.

Flow rate. The flow rate was measured for selected mixtures over a 5 to 65 C temperature range for the spray nozzle types and sizes shown in Table 2. Figure 1 shows the pressure and temperature control equipment used for the flow tests. A pressurized tank was used to enclose a 3.8 l aluminum vessel containing a mixture. Temperature controlled water was circulated through a heat exchanger to maintain the temperature of the mixture at the desired level. Temperature was monitored with a digital electronic thermometer.

Nozzle flow rates were measured by filling the internal container with the test mixture, bringing the water bath to the desired temperature and regulating the pressure to a selected value. When the temperature of the mixture was stable, the release valve was opened and the flow from the test nozzle was collected. The mass of flow was collected for 30 sec and was weighed with a Scientech 222 Electronic Balance. Each test was replicated three times, averaged, and the volumetric flow rate calculated for each respective temperature.

Another procedure, used for the 15% and 30% Soybean oil-Ambush® 4-OIL mixtures, consisted of bringing the mixture to either 0 or 70 C, whichever was closest to the test flow temperature. The mixture was placed in the pressure vessel, the pressure adjusted to the desired value and the valve opened, allowing the liquid to flow. During flow, temperature of the liquid at the nozzle was monitored and recorded approximately five times every minute. After about one liter had been discharged and a steady-state temperature reached, a timed sample was collected and the volumetric flow rate calculated. The liquid was returned to the pressure vessel and the procedure repeated for each temperature.

TABLE 1

Vegetable Oil Blank-Formulation Mixtures Used in Tests

1	Soybean oil (100%)—once-refined
2	Soybean oil (80%) and Ambush® 2E (20%)
3	Soybean oil (93.6%) and Ambush® 4-OIL (6.4%)
4	Soybean oil (85%) and Ambush® 4-OIL (15%)
5	Soybean oil (70%) and Ambush® 4-OIL (30%)
6	Soybean oil (86.5%) and Pounce® 4-OIL (13.5%)
7	Soybean oil (93.6%) and Xylene (6.4%)
8	Cottonseed oil (100%)—once-refined
9	Cottonseed oil (80%) and Ambush® 2E (20%)

TABLE 2

Spray Nozzles Used in Flow Rate Tests

Nozzle Type	Rated Flow[a] (4 min)	Manufacturer and Designation	Material
Flat	0.38	Spraying Systems Teejet® 8001	Stainless steel
	0.57	Spraying Systems Teejet® 80015	Stainless steel
	0.76	Spraying Systems Teejet® 8002	Stainless steel
Even-flat	1.51	Delavan EVEN-FLAT LE-4	Stainless steel
Hollow Cone wide-angle	0.76	Spraying Systems Whirljet® 1/8 BSS	Stainless steel

[a]Catalog data based on water at 276 kPa.

RESULTS

Specific gravity. Figure 2 shows the measured temperature-induced change in specific gravity of some selected soybean oil mixtures. Specific gravity decreased inversely approximately 5% over the temperature range of 5 to 70 C. No specific gravity data were measured for the cottonseed oil mixture. However, a response similar to that of soybean oil would be expected because cottonseed oil is only slightly less dense than soybean oil.

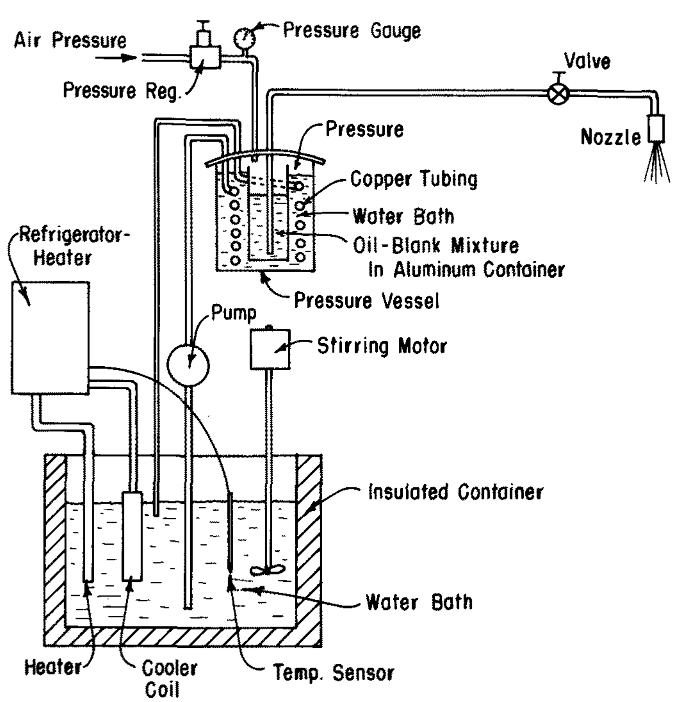

FIG. 1. Apparatus used for measuring flow rate at constant temperature.

Viscosity. Information regarding the viscosity of vegetable oil mixtures is of interest because hydraulic nozzles produce shear in the flowing liquid as the spray is developed. Shear forces of importance develop at the nozzle-air flow interface of aircraft spray systems in operation. These forces directly influence the drop formation and the drop size distribution in the spray.

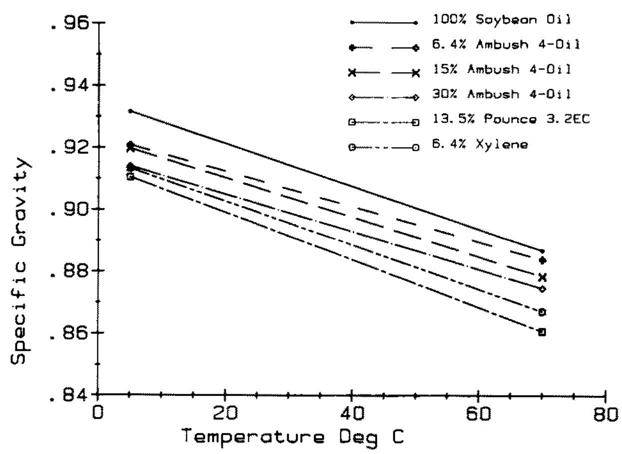

FIG. 2. Temperature effect on the specific gravity of selected soybean oil mixtures.

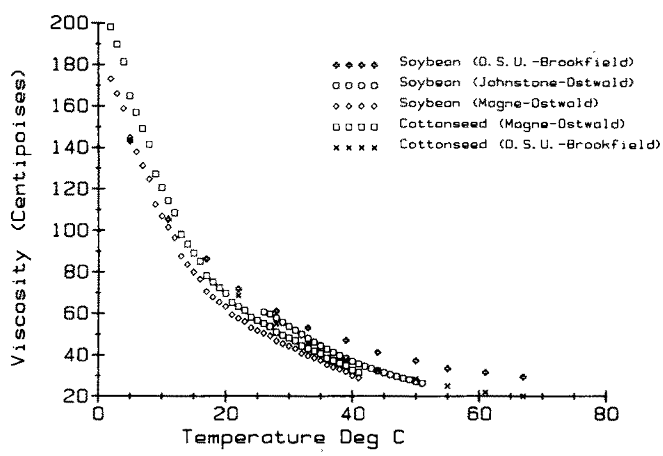

FIG. 3. Viscosity-temperature curves for once-refined soybean and cottonseed oil comparing two methods of viscosity measurement.

Viscosity-temperature curves for once-refined soybean and cottonseed oil are presented in Figure 3. Three of the curves, soybean oil (Johnstone-Ostwald), soybean oil (Magne-Ostwald) and cottonseed oil (Magne-Ostwald), were obtained from the literature (2,3). They represent viscosity-temperature relationships as determined with a modified Ostwald viscometer which relates timed fluid flow (through a tube) with viscosity. The other two were obtained experimentally using a Brookfield viscometer that uses a rotating spindle and relates the torsional resistance of a spindle to the viscosity. This method involves forced dynamic shear in the measurement and gives slightly higher viscosity readings than the Ostwald method.

Vegetable oil mixtures resulted in decreased viscosities (Figs. 4 and 5). All curves of Figures 4 and 5 were determined with the Brookfield equipment and thus can be used to relate the viscous properties of the mixtures. The viscosity of the Ambush® 2E and 4-OIL in soybean oil mixtures fell along the same line as did the Pounce® and Xylene mixtures. Above 50 C, the soybean oil mixtures exhibited approximately the same viscosity. The cottonseed oil mixture resulted in reduced viscosity over the temperature range. Also, cottonseed oil and the cottonseed oil mixtures featured less viscosity than the soybean oil counterpart over the entire temperature range studied. A least squares fit of the data is presented in Table 3. The equations are of the form: Viscosity (Centipoises) = $A \times (°C)^B$.

Flow rate. Orifice flow is a function of orifice diameter and edge characteristics as well as fluid properties of viscosity and density. Most aircraft spray nozzles are more complex than simple orifices in that they include components which are designed to direct the flow of liquid into a swirl prior to entering the orifice. These designs result in hollow cone sprays. Others have oval-shaped openings to force the spray into a fan or flat shape. Regardless of the design, aircraft nozzles discharge into a relatively high velocity airstream that results in varying amounts of wind shear across the emerging fluid stream. The total effect of such external shear on flow rate is not known. However, viscous shear within a fluid is known to affect the flow rate. Temperature has significant influence on the flow of vegetable oil from such an orifice system because it

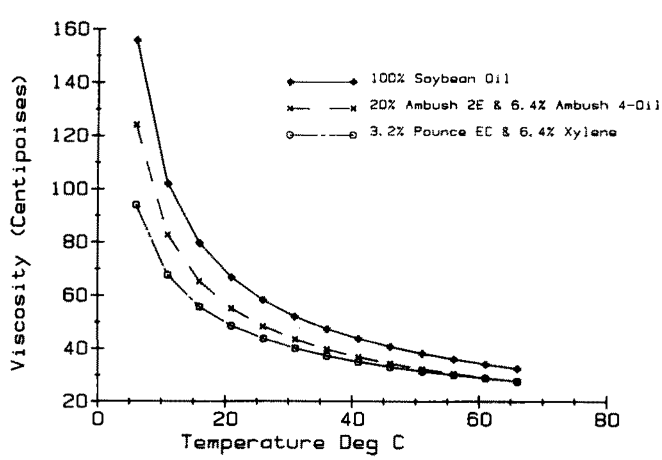

FIG. 4. Viscosity-temperature curves for selected soybean mixtures.

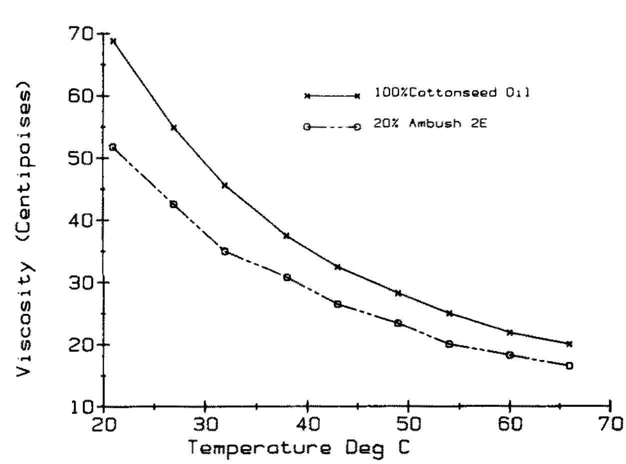

FIG. 5. Viscosity of cottonseed oil and an Ambush® 2E mixture.

TABLE 3

Viscosity-Temperature Equations Constants for Vegetable Oils and Mixtures

	A	B	R-sqr
Soybean oil (100%)	417.12	−0.612	0.968
Soybean oil-Ambush® 2E (20%)	318.52	−0.586	0.974
Soybean oil-Ambush® 4-OIL (6.4%)	327.00	−0.592	0.990
Soybean oil-Pounce® 3.2EC (13.5%)	202.00	−0.476	0.958
Soybean oil-Xylene (6.4%)	200.62	−0.467	0.973
Cottonseed oil (100%)	2050.10	−1.104	0.998
Cottonseed oil-Ambush® 2E (20%)	1196.30	−1.018	0.996

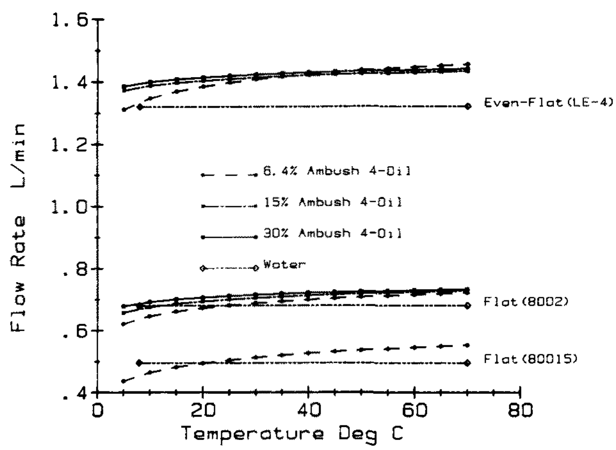

FIG. 6. Flow rate as a function of temperature for water and selected soybean oil—Ambush® 4-OIL mixtures through three different flat nozzles operated at 207 kPa.

directly affects the viscosity and thus the shear action within the orifice.

The fitted curves of Figures 6 through 8 represent flow rates measured for selected mixtures. The temperature effect on flow rate was similar for both vegetable oil mixtures. However, above a given temperature, depending on mixture concentration and orifice size, the flow rate of soybean oil mixtures exceeded that of water (Fig. 6). The flow rate of the cottonseed oil mixture remained less than the flow rate of water at temperatures below 70 C (Fig. 7).

The effect on flow rate due to concentrations of Ambush® 4-OIL in soybean oil is presented in Figure 6 for nozzle tips 8002 and LE4. Similar curves would be expected for the other formulations, as indicated by the data in Figure 6.

Flow rate curves for a hollow cone wide-angle nozzle with mixtures of Pounce® 3.2EC and Ambush® 4-OIL in soybean oil are presented in Figure 9. At a constant pressure of 173 kPa, the flow increased with temperature for both mixtures until a temperature was reached at which viscous forces were overcome within the nozzle swirl chamber and the characteristic cone spray pattern developed. Beyond this point, flow reduction occurred for both mixtures, but at slightly different temperatures. This nozzle performance is consistent with that described by Marshall (4). Hollow

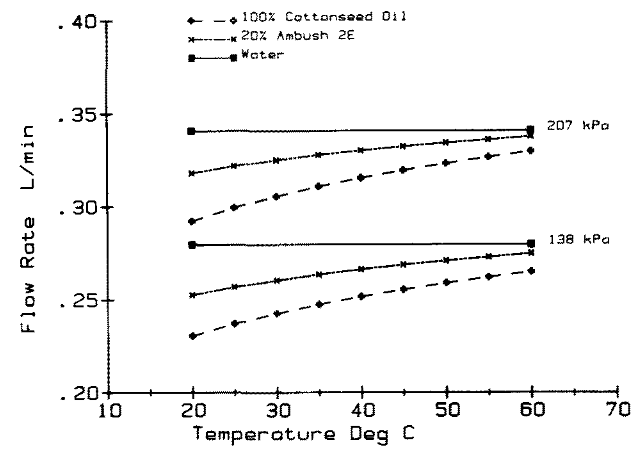

FIG. 7. Flow rate as a function of temperature for water, 100% cottonseed oil and a 20% Ambush® 2E mixture from a flat (8001) nozzle operated at 138 and 207 kPa.

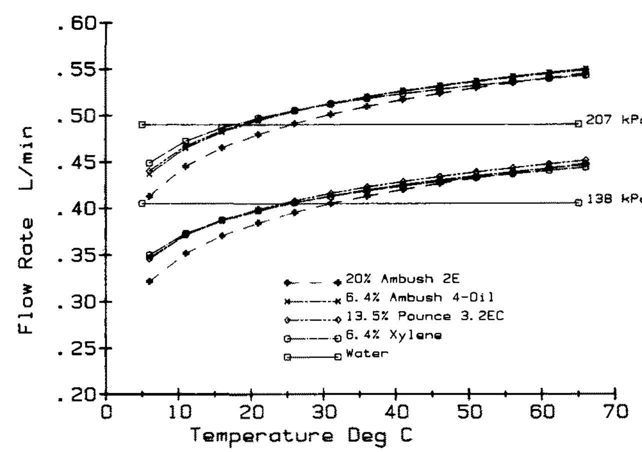

FIG. 8. Flow rate as a function of temperature for selected soybean oil mixtures through a flat (80015) nozzle at 138 and 207 kPa.

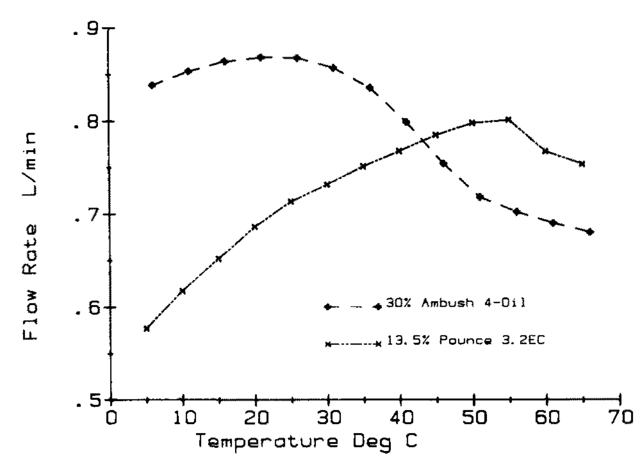

FIG. 9. Flow rate as a function of temperature of two different soybean oil mixtures through a hollow cone wide-angle (1/8 BSS1) nozzle at 173 kPa.

cone wide-angle nozzles are designed for liquid to be emitted in an annular ring. For this type of nozzle, the effect of decreasing viscosity (due to a temperature increase in this case) where an air core cannot form is an increase in flow. Continued viscosity reduction beyond that where an air core forms results in a flow rate reduction.

Similar flow characteristics would be expected for all hollow cone nozzle systems that depend on swirling action of the fluid to develop the hollow cone pattern. These types of nozzles should be avoided when spraying vegetable oil diluents, unless some type of spray tank liquid temperature control is provided.

Figures 10 through 12 present curves of flow rate error for selected mixtures with the flat and even-flat nozzles. Assuming an aircraft spray system pressure were selected for a desired flow rate using published data for water, the approximate error in application rate of vegetable oil due to temperature of the tank mix could range from about −15% at 5 C (as compared with water) to +12% at 65 C (relative to water). This error is essentially independent of pressure over the normal operating pressure range but is somewhat dependent on nozzle size and concentration of the mixture.

To develop an expression for the approximate error in orifice discharge due to fluid temperature variation and the necessary pressure correction, consider the orifice flow equation:

$$Q = CA\sqrt{P} \qquad [1]$$

where Q = flow rate (l/min)
C = orifice coefficient
A = area of orifice (cm^2)
P = pressure of fluid (kPa)

The approximate error in flow due to temperature variation may be calculated by the following expression:

$$E\% = \frac{(Q_t - Q_w)\,100}{Q_w} \qquad [2]$$

where E% = percent error in flow
Q_t = Flow at a given temperature (l/min)
Q_w = flow of given orifice for water (l/min)

Negligible error in water flow rate is induced by temperature changes within the range 0 to 70 C. Error is based on the deviation from that of water, because standard practice is to use published nozzle flow data with water.

Substituting for Q in equation 2

$$E\% = \frac{C_m A\sqrt{(P_m)} - C_w A\sqrt{(P_w)}\,100}{C_w A\sqrt{P_w}}$$

Thus for a selected mixture temperature and for a pressure, P, and an orifice diameter, A,

$$E\% = \frac{C_m - C_w\,100}{C_w} \qquad [3]$$

where C_w = Discharge Coefficient for water ($C_v = Q_w/A\sqrt{P_w}$)
and C_m = discharge Coefficient with the fluid at given temperature. ($C_m = Q_m/A\sqrt{P_m}$).

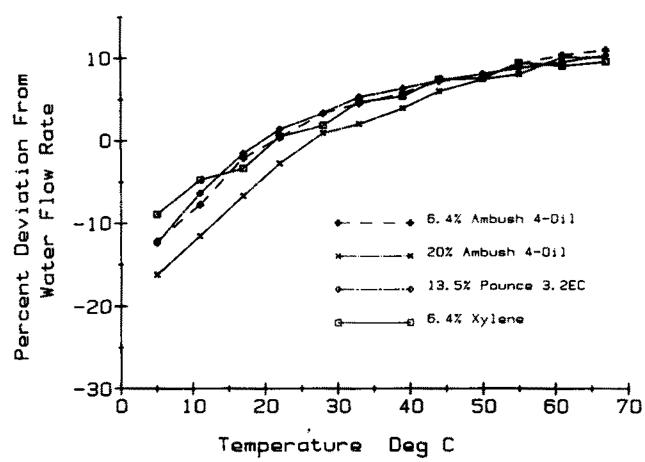

FIG. 10. Flow rate error as a function of temperature for selected soybean oil mixtures through a flat (80015) nozzle at 207 kPa.

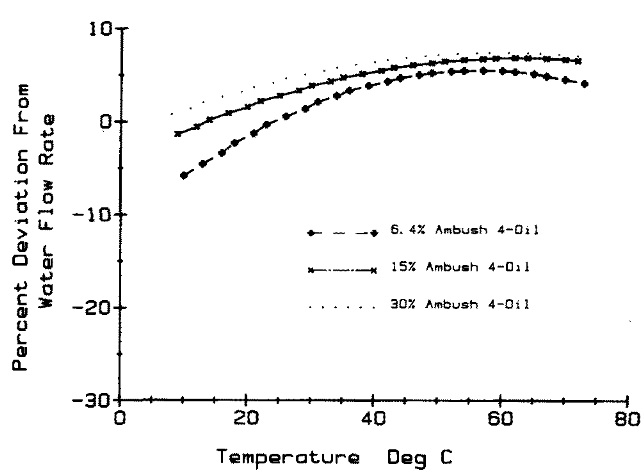

FIG. 11. Flow rate error as a function of temperature for selected soybean oil mixtures through a flat (8002) nozzle at 207 kPa.

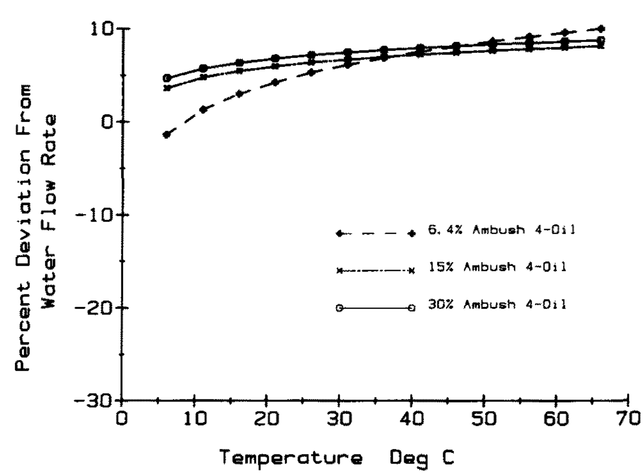

FIG. 12. Flow rate error as a function of temperature for selected soybean oil mixtures through an even-flat (LE-4) nozzle at 207 kPa.

Variation in flow at constant pressure is a function of C, all other parameters remaining constant. Thus, by computing values of C for corresponding temperatures, an expression for C in terms of temperature may be developed for each mixture and orifice. A geometric least square fit for all data for each orifice was obtained as an approximation for C in terms of fluid temperature. The following equations represent those best fit expressions for C based on all flow data for the various mixtures tested at 138 and 207 kPa pressure.

Cottonseed oil (80%)-Ambush® 2E(20%) with flat (8001) Nozzle

$$C_m = 5.236\ T^{0.0655} \qquad [4]$$

Soybean Oil-All Mixtures—with flat (80015) Nozzle

$$C_m = 5.1953\ T^{0.0979} \qquad [5]$$

All mixtures of Soybean Oil-Ambush® 4-OIL—with flat (8002) nozzle

$$C_m = 6.582\ T^{0.0367} \qquad [6]$$

All mixtures of Soybean Oil-Ambush® 4-OIL—with even-flat (LE4)

$$C_m = 6.321\ T^{0.0364} \qquad [7]$$

Expressions 4-7 may be used to develop approximate pressure correction values based on fluid temperature and published nozzle flow data for water. Setting the flows for water and oil mixture equal and solving for the required pressure to equal the water flow rate:

$$Q_m = Q_w$$
$$C_m A\sqrt{P_m} = C_w A\sqrt{P_w} \qquad [8]$$
$$P_m = \frac{C_w^2\ P_w}{C^2_m}$$

where P_m = pressure for mixture (kPa).
P_w = pressure for water (kPa).

Substitution of appropriate C_m values (Eq. 4-7) and proper C_w value (Eq. 3) for the orifice in question will result in the approximate pressure required to adjust the flow rate to that of water.

Figure 13 shows one solution to Equation 8 for a selected nozzle and mixture that may be used to estimate the correct boom pressure to match that for water. Graphs for the other nozzles and mixtures can be constructed in a similar manner.

From these results, we have made the following observations:

- Vegetable oil properties of specific gravity and viscosity vary inversely with temperature either alone or in mixtures of blank-formulations of Ambush® 4-OIL, Pounce® and Xylene. Specific gravity varied linearly approximately 5% over the temperature range of 5 to 65 C. Viscosity varied geometrically approximately 300 to 420% over the same temperature range, depending on the mixture.

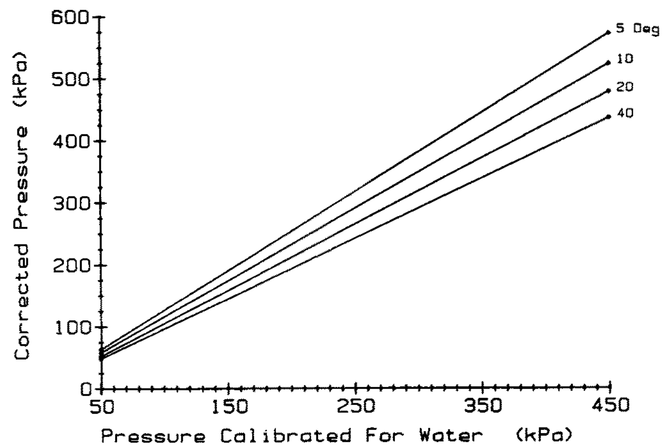

FIG. 13. Pressure corrections for different temperatures of a cottonseed oil-20% Ambush® 2E mixture through a flat (8001) nozzle.

- The vegetable oil mixture resulted in reduction of viscosity over the temperature range tested with greater viscosity reduction at the lower end of the temperature range.
- Flow rate error varied geometrically with temperature from −20% to 12% for the flat (80015) nozzle, −15% to 7% for the flat (8002) nozzle, and from −2% to 12% for the even flat (LE4) nozzle over the temperature range of 5 to 65 C.
- Flow rate error was most sensitive to mixture temperature for the smaller nozzle orifices. Therefore, it is recommended that the largest orifice consistent with drop size requirements be used for vegetable oil mixture applications.
- Nozzles that depend on an internal swirling action to develop a hollow cone spray pattern are not recommended for oil application due to the flow rate sensitivity to temperature-induced viscosity effects.

ACKNOWLEDGMENTS

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