Ice skating rink permits studies on

Orchard Heater Plume Heights

under controlled laboratory conditions

Todd V. Crawford and Arthur S. Leonard

Previous tests have shown that 75% to 90% of the heat of combustion of the fuel oil burned in an orchard heater goes into producing the hot gases which rise as a plume vertically above the heater. As these hot gases rise, they cool by mixing with the surrounding air. Cooling is rapid until a height is reached where the temperature of the plume is near the temperature of the adjacent air. If the temperature of the air over the crop increases with height at this point—if a temperature inversion exists—continued upward movement of the gases soon brings them to a height where the surrounding air has the same temperature as that of the plume. Above this point, the plume's gases are actually colder than the adjacent air. Thus the gases in the plume are heavier than the surrounding air and their momentum is dissipated. This soon brings the upward motion to a halt. Then the gases fall part way back to the height at which they had the same temperature as the surrounding air and spread out at that level. This height at which the gases spread out and the height at which the upward motion ceases are measures of the depth of the air over the crop being heated.

In the development of frost protection systems, more information on the behavior of these plumes is needed.

Two different investigators have proposed theoretical descriptions of the behavior of a buoyant plume under temperature inversion conditions and for the case of no wind. In both treatments, the strength of the temperature inversion—temperature change per foot—is taken as a constant with height to well above the top of the plume. In nature, the strength of the temperature inversion usually decreases with height under frost conditions. The temperature inversion decreases to zero at some height above the crop land which then defines the top of the inversion layer. If the temperature of the hot gases in the plume does not become equivalent to that of the surrounding air within the inversion layer, then the foregoing description does not hold and the plume continues to rise almost indefinitely. The strength of the temperature inversion has its greatest effect on the vertical motion of the gases in the upper part of the plume; in the lower part, the buoyancy of the gases is so great that the strength of the temperature inversion has little effect on their upward motion.

Although the two theoretical formulations are somewhat different, they do result in almost identical formulae for the maximum height of the plume—the height at which the vertical velocity equals zero. A preliminary objective of current research was to check experimentally the validity of the theoretical approaches.

The instrumentation problem of lo-

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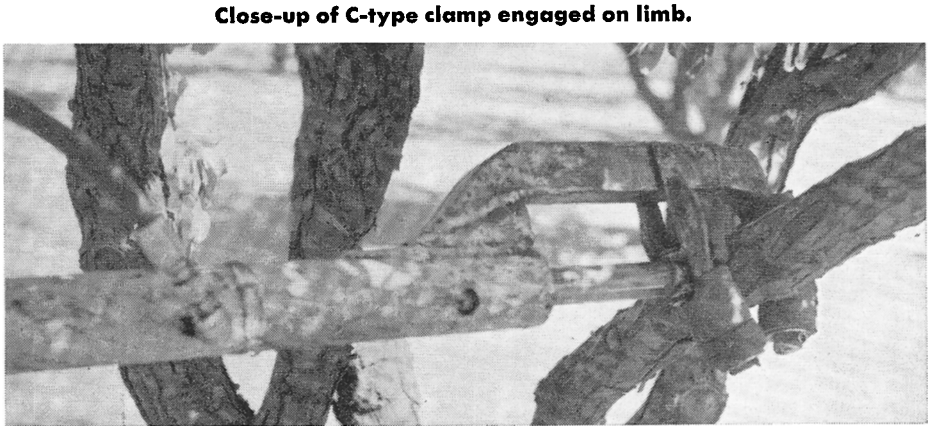
damage to the tree at the point of attachment. Minimum damage results from the linear motion for clamping. Regardless of limb size, the force applied to the limb is nearly in line with the direction of force application. Thus, the total force, and also any shear forces on the limb, are minimized. In addition, the hydraulic circuit used for clamping is also designed to yield a minimum force on the limb. This is accomplished by closing the clamp with a low pressure, then blocking the oil flow so as to be able to develop the higher pressures and forces required.

Field tests indicated that the unit is comparable to boom shakers with respect to harvest rate and fruit removal but pointed out the advantages:

Close-up of C-type clamp engaged on limb.



1. A separate propelling vehicle is not required, thus reducing the cost.

2. Provided the incline of the shaker is not great, the mounting effectively isolates the vibration from the catching frame, reducing maintenance.

3. The C-type clamp, together with the flexible mounting, reduces bark damage.

Further work is needed toward optimizing shaker design, considering both power consumption and reactive loads. For example, the rotating-mass design that was used requires less power than the piston-crankshaft design that was used. Also, the reactive load is a function of the weights and the electricity.

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The above progress report is based on Research Project No. 1717.

HEATER PLUMES

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cating, following and measuring the plume of an orchard heater operating outdoors is very difficult. The lack of control of the many variables outdoors also makes this approach one of questionable value.

If, on the other hand, a heater of smaller size—a model—could be used and operated under the more favorable conditions that could be had under a laboratory setup, those objections could be overcome. The use of models would reduce the volume of space requiring instrumentation to more reasonable dimensions, would permit more control over the many variables, would allow greater flexibility in the design of experiments, and would not limit data collection to the few frost nights each year.

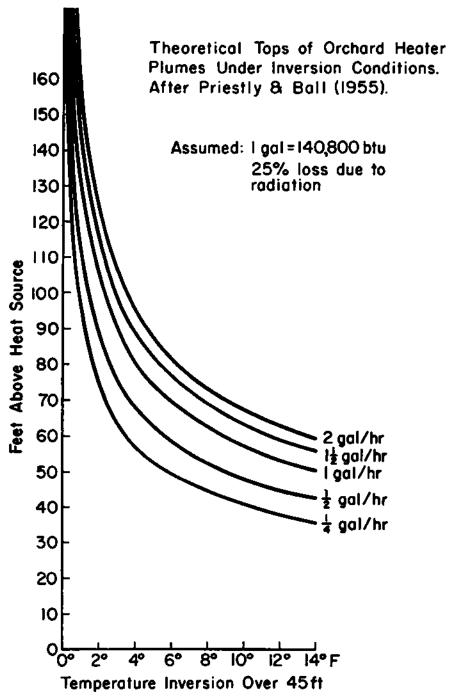
The simulation of frost conditions requires that model studies be conducted within a fluid in which there is a stable density stratification, ideally air with a temperature inversion. To preserve the similarity of the flow pattern in the model system, the strength of the temperature inversion must be scaled up as the size is reduced from that of the full scale system. Because of the difficulty in meeting this requirement, the size of the model system cannot be reduced very greatly. Therefore, an ice skating rink was obtained for use as a research laboratory.

The ice surface creates a temperature inversion similar to that found in nature, under typical frost conditions, though about 1/12 as deep a layer of air. Therefore a geometric scale factor of 1/12 was used.

The plume from the model orchard heater was rendered visible by a schlieren optical system which permitted visual observations, and photographic recording on movie film. In addition to the movies, data was collected on the heat output of the model orchard heater, temperature inversion, and so forth. Experiments were done under a wide range of heat output by the model heater and through some range in the strength of the temperature inversion.

The data provided reasonable—within 10%—confirmation of the theory. Therefore, the theory which fitted the data the best was used to prepare the accompanying graph. As an example, the top of the plume from an orchard heater burning 0.5 gallon of fuel oil per hour, under a temperature rise of 12° F. in 45′—the change in temperature per foot is assumed a constant from 5′ to 50′ above the ground—is 44′ above the heater. The hot gases are confined to this layer of air and consequently do a fairly efficient job of warming.

As another example, consider the same heater fuel consumption but with a temperature rise of only 4° F. in 45′. In this case, the graph shows that the top of the plume would be 68′. The temperature increase in the air near the crop is now less as the same amount of heat is being used to heat a deeper layer of air.



The theoretical height of orchard heater plumes is shown as a function of the rate of fuel oil consumption and the temperature increase in 45′ going upward from the heater.

Doubling the fuel consumption to 1.0 gallon per hour in the two examples, raises the top of the plume to 54′ and to 80′. Some of the additional heat being released is then used to heat this increase in depth of air. As the strength of the temperature inversion decreases with height, an increase in the plume height, due to supplying more heat, will bring the plume into regions of weaker inversions. Thus the plume will rise even farther than that indicated on the graph. Particularly in the case of temperature inversions which are already weak, this causes the hot gases to rise to such a height that much of the heating value of the fuel is used in heating air too far above the crop to be of much benefit. In cases where a high fuel consumption causes the hot gases within the plume to rise through a region with a strong temperature inversion into a region containing a much weaker inversion, a decrease in the fuel consumption could cause the plume to be confined to the relatively shallow strong temperature inversion layer and hence increase the heating efficiency. There have been cases reported where decreasing the fuel consumption has increased the temperature of the air immediately over the crop.

The temperature of the air can only be raised by the plume's gases when these gases are warmer than the surrounding air. Therefore, the effective depth of air over the crop being heated will be less than that indicated on the graph. The theory predicts that the temperature of the gases in the plume is equal to the temperature of the surrounding air at 71% to 76% of the height of the top of the plume.

Wind will markedly reduce the maximum height of the plume. A bent-over plume has a larger exposed surface moving upward through the undisturbed air and the turbulence in the natural wind speeds up the mixing of the plume's gases with the surrounding air. Although decreasing the depth of air being heated, a persistent wind from one direction will increase the volume of air to be heated. The larger the area being heated, the smaller is this edge effect.

The use of models in studies of buoyant plumes in a temperature inversion and under calm conditions provided reasonable confirmation of theoretical formulas predicting the maximum height of the plumes.

Under calm conditions, it appears that operating orchard heaters above 0.5 gallon per hour in the deciduous orchards of central and northern California would be inefficient use of fuel oil. An increase in the fuel consumption, however, does increase the radiant output of the heaters which, in some cases, might be the only type of heat protecting the crop; for instance, in a strong, cold wind. But only a small per cent of the heat output from a heater is in the form of radiant heat—approximately 10% for lard pail and 25% for tall stack types of heaters.

Rates of 1.0 to 1.5 gallons per hour might be used efficiently under the stronger winter temperature inversion conditions of the citrus orchards of southern California.

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William Kerth, North Sacramento, provided the ice skating rink for use as a research laboratory for the above experiments.