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P.O. BOX 245, BERKELEY, CALIFORNIA 94701

FIRE ENVIRONMENTAL TEST CHAMBER: its design and development

Clifford J. Auvil

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The Fire Environmental Test Chamber at the Forest Fire Laboratory, Riverside, California, is a self-contained controlled facility that can produce a wide variety of conditions for testing wildland fuels. Basically a low-speed wind tunnel, the test chamber can—within certain limits—produce airflow, solar radiation, temperatures, and relative humidity (*table 1*). It can duplicate in any combination or desired sequence these key factors that affect the flammability of wildland fuels.

The interaction between fuels and these factors can be studied by placing a fuel sample within the test chamber. The sample can be treated for any time period appropriate to the specific experiment. As conditions change, the fuel sample is monitored continuously to determine its water content and, correspondingly, its flammability.

First installed in 1962, the test chamber has since then undergone several changes to meet experimental requirements over and above its original capabilities. The basic chamber was a wind tunnel with the additional capabilities of producing controlled air, temperature, and relative humidity in the main loop. A secondary loop dehumidified the air.

This note summarizes experience in the design and modification of the test chamber. It outlines its major characteristics, and provides a guide to those who may wish to develop or acquire such a test facility (*fig. 1*).

CONTROLLED LOW-SPEED AIRFLOW

The primary design consideration in the development of a test chamber is the delivery of non-turbulent airflow to the work area.¹ This air is first conditioned for temperature and humidity. The original test chamber used a 3-horsepower alternating-current motor to drive a blower which circulated air through the chamber. Velocity of the circulating air was governed by opening or closing an iris valve mounted directly upstream from the blower. This

Abstract: The Fire Environmental Test Chamber at the Forest Fire Laboratory, Riverside, California, can duplicate under controlled conditions the key factors that affect the flammability of wildland fuels. Within certain limits, it can produce air flow, solar radiation, temperatures, and relative humidity. First developed in 1962, the test chamber has since then undergone several modifications to meet requirements over and above the original capabilities. The characteristics of the test chamber and nature of the changes are explained. Recommendations on design and development are offered.

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Retrieval Terms: fire behavior; fire environment; fuel samples; simulation; test chambers.

Table 1—Operating ranges of the Fire Environmental Test Chamber at the Forest Fire Laboratory, Riverside, California

Dry bulb temperature range	25° F. to 120° F.
Dry bulb temperature control tolerance	± 1° F.
Dry bulb temperature change rate	Min. 40° F./hr.
Dew point temperature range	-23° F. to +20° F. @ 25° F. dry bulb, and 39° F. to 90° F. @ 120° F. dry bulb with comparable limits between these dry bulb temperatures.
Dew point control tolerance	± 1° F.
Dew point temperature change rate	Min. 10° F./hr.
Air flow	3.5 to 100 ft./min. with automatic control from 5 ft./min. to 1,000 ft./min.
Wind speed control	± 10% or ± 5 ft./min.
Radiant energy	From about 0.19 to 1.94 cal./sq. cm./min. predominantly infrared.
Radiant energy control	± 5% of indicated value
Heat sink range	0° F. to 75° F.
Heat sink tolerance	± 5° F.

control was acceptable for airflow velocities from 700 to 1,200 feet per minute, but tests of airflows from 3.5 feet to 700 feet per minute were subjected to an

unacceptable level of turbulence and boundary layer separation. In many instances, this separation made the test results inconclusive.

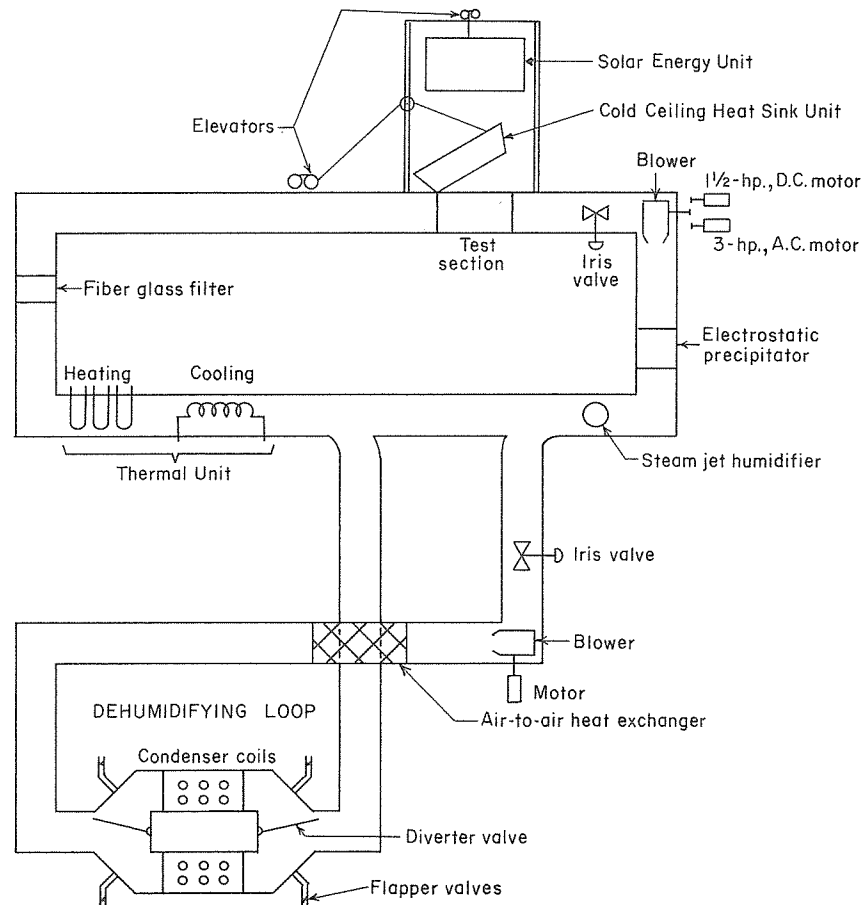


Figure 1—Main components for air circulation in the Fire Environmental Test Chamber include the solar energy unit, cold-ceiling heat-sink unit, electrostatic precipitator, and dehumidifying unit.

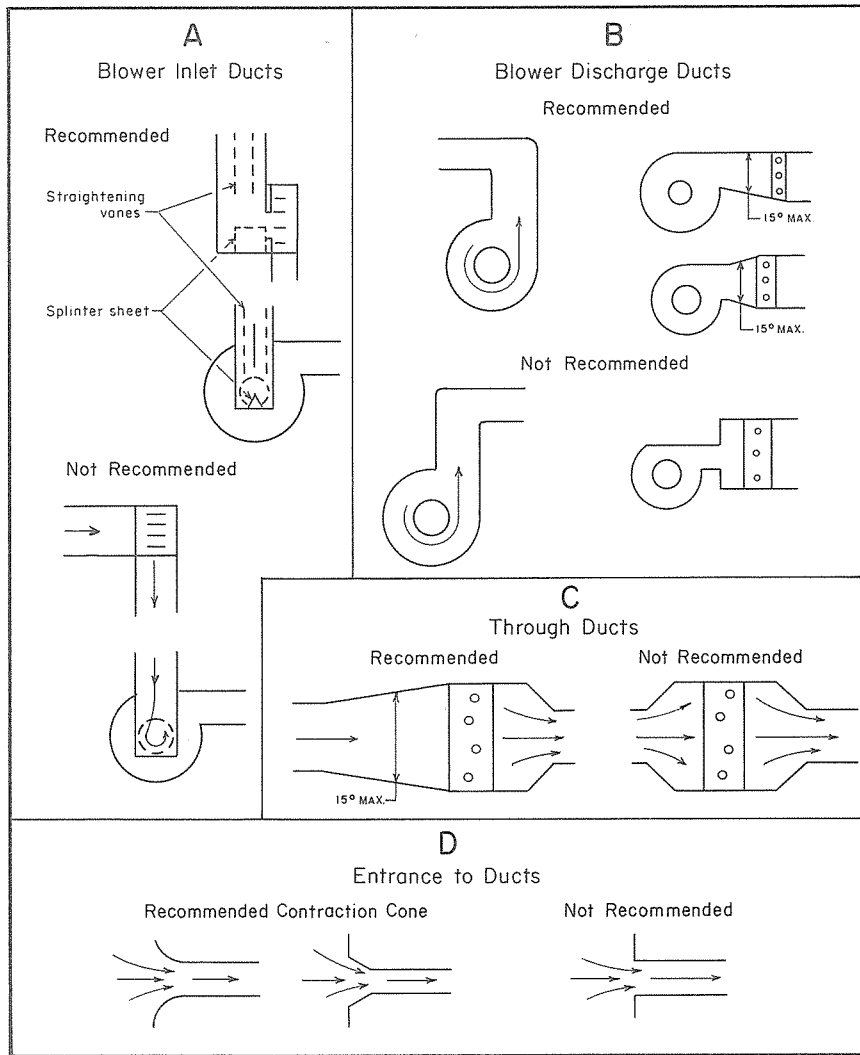


Figure 2—Proper duct design is necessary to avoid excess turbulence in airflow in the test chamber. Illustrated are some designs recommended and not recommended: A—fan blower inlet; B—fan blower discharge; C—airflow through ducts; D—entrance to ducts.

A study of turbulence was conducted by using smoke as a tracer. Punk was used to generate smoke, and tests were conducted at high and low airflow velocities. The punks were placed, 1, 2, and 4 inches above the flow. The distance between the work area and the iris valve was 25 inches. Owing to this short distance, the boundary layer separation extended into the work area. This extension created undesirable results in the samples being tested as it affected proper airflow.

To reduce the turbulence in the lower velocity ranges, technicians installed a variable speed 1-1/2-horsepower direct-current motor to drive the blower. This motor used an armature voltage control system

which responds to a variac voltage regulator; the variac regulator in turn responds both to the pitot tube—an airflow sensing unit—for constant airflow velocity during a test, and to manual controls for any changes in airflow velocity made by the operator.

Other design factors that must be considered in achieving the desired laminar, non-turbulent airflow are these: (a) duct shapes that induce turbulence (*fig. 2*); (b) airflow straighteners upstream of the blower that reduce airflow eddy currents about the blower; (c) contraction and divergence cones at the work area; (d) coarse and fine airflow straighteners upstream of the work area.² They all contribute to the effective elimination of boundary separation, in-

adequate mixing, excessive turbulence, and any other undesirable airflow conditions that may mar test results.

AIRFLOW RELATIVE HUMIDITY CONTROL

Relative humidity control of airflow was the most complex of the design requirements. The addition or reduction of moisture content in airflow must be done in a way that ensures accurate control of the desired relative humidity at any level (*table 1*); and does not excessively tax other chamber components.

Increasing the moisture content in the airflow may be accomplished in several ways; for example, air bubbling through water, dry air passing over a pan of water, or a water atomizer. In each case, raising the water temperature increases the evaporation rate, resulting in higher humidity. Investigation of existing humidity generators indicated that the best method to add to moisture is by vapor.³ Therefore, a small steam generator which injects hot, dry steam into the airflow just downstream of the electrostatic precipitator in the main loop was added.

Decreasing the moisture content in the airflow was a more difficult task. The best methods are refrigeration and desiccant drying. Desiccant drying will adequately control moisture content between 10 percent at 50°F. up to 75 percent at 10°F. without requiring special equipment. But low dewpoints cannot be reached without the use of special equipment, or desiccants which require extremely high temperatures for reactivation.⁴

Refrigeration dehumidifiers provide excellent moisture reduction in airflow if the dehumidifying unit includes a good defroster. The dehumidifying system developed for the test chamber is in its own loop (*fig. 1*) and uses a 10-horsepower compressor to drive the refrigeration system (*fig. 3*).

Moisture is reduced in the airflow by opening the dehumidifying loop iris and starting the loop blower. The airflow is drawn into the loop and passes over an air-to-air heat exchanger and into one bank of dehumidifying refrigerator coils.

The dehumidifying coils freeze the moisture in the passing airflow and collect the resulting ice. When the ice creates a 1-inch water pressure differential, a switching device actuates a butterfly valve system, which routes the airflow to the second bank of dehumidifying coils. After a 35-second delay the first set of coils undergoes a melting process.

The first bank of coils remain exposed to outside room air until 90 seconds before the process is repeated. This switchover diverts the airflow back from the second bank of coils. The second bank of coils

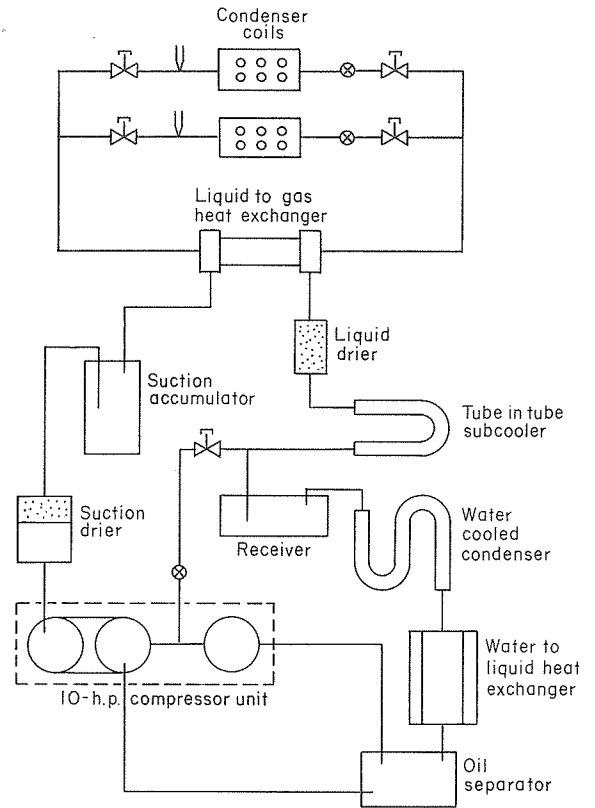


Figure 3—The dehumidifying unit of the test chamber helps reduce moisture in airflow. A 10-hp. compressor drives the unit.

then undergoes the same ice melting process just completed by the first bank of coils.

After leaving the dehumidifying coils, the airflow passes under the air-to-air heat exchanger, to acquire some of the sensible heat lost during moisture removal. It then returns to the test chamber main loop and is conditioned by the temperature control system to reestablish the correct temperature required for the test in progress.

AIRFLOW TEMPERATURE CONTROL

Control of airflow temperature was the simplest of all design requirements to satisfy. A temperature control system, consisting of a series of cooling coils in the test chamber main loop upstream of a series of Inheco⁵ heating units, provides adequate thermal control to meet parameters specified in (*table 1*).

Situated downstream from the humidifying and dehumidifying control areas, the temperature control provides the final conditioning factor to be applied to the airflow before entry into the work area. Placement of this system is critical because the airflow is heated or cooled as it passes through each of the earlier steps. Furthermore, these steps cannot impart

the required temperature to the airflow; therefore, the proper temperature must be established as the final conditioning factor in the process.

The cooling system is driven by a 3-horsepower refrigeration compressor and is controlled by a test chamber thermostat set to the desired temperature (fig. 4). Because the thermostat also controls the heating unit, it can select the proper unit either to raise or to lower the temperature of the airflow to meet the required test temperature.

The Inheco⁵ heating unit consists of three 1.5-kilowatt electric heating elements placed in ducting in front of the filter which is upstream from the test section. Therefore, the air is mixed before it enters the test section.

SOLAR RADIATION AND COLD CEILING HEAT-SINK

To simulate the solar heating and night-time cooling, the designers incorporated a solar energy unit and cold-ceiling heat-sink unit into the test chamber.

Located in time-controlled interacting elevator, the solar energy unit is lowered to the top of the work area (fig. 5), and operates for a specific time period under pre-set conditions, and then shuts down. The test chamber blowers are shut off for a pre-determined time to allow all airflow in the test chamber to stop, thus minimizing the introduction of unconditioned air into the work area during the unit change. The interacting elevator system then raises the solar energy unit and lowers the cold-ceiling heat-

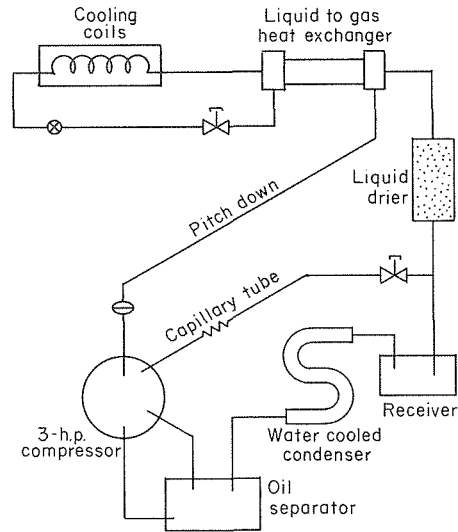


Figure 4—The cooling system for the main loop cools air in the test chamber's test section. A thermostat controls the temperature.

sink unit to the top of the work area (fig. 6). The test chamber blowers are then started, and the heat-sink operates for a specific time under preset conditions.

The environmental conditions are recorded on a Honeywell pneumatic potentiometer for a 24-hour period. The recording period may be extended by using a strip chart of any desired time duration. Or it can be done by replacing daily the 24-hour circular graph during the test period; this change can be made without interrupting the test in progress.

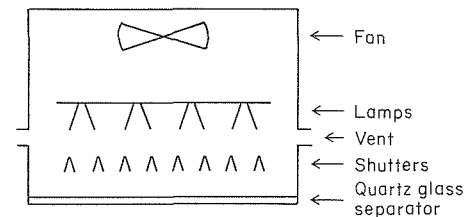
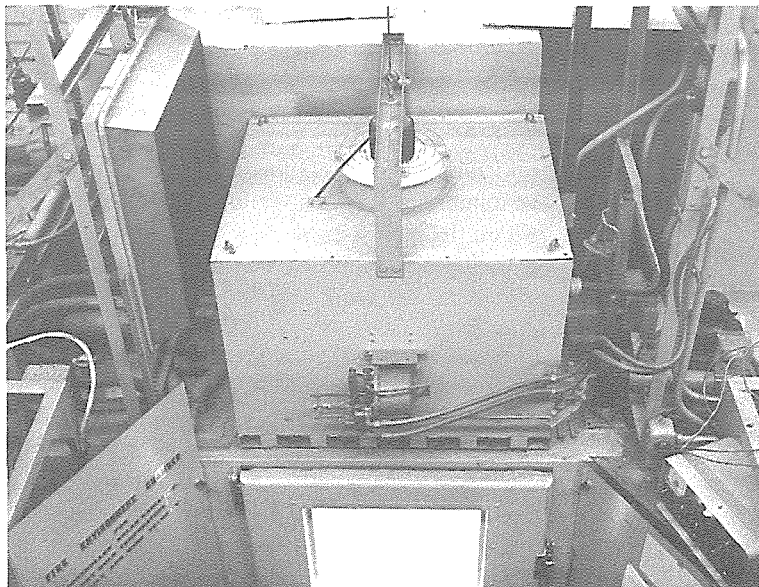


Figure 5—The solar radiation unit simulates solar heating in the test chamber. It is lowered to the top of the work area.

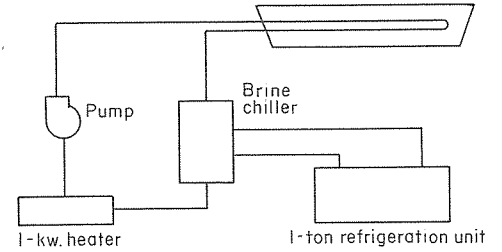
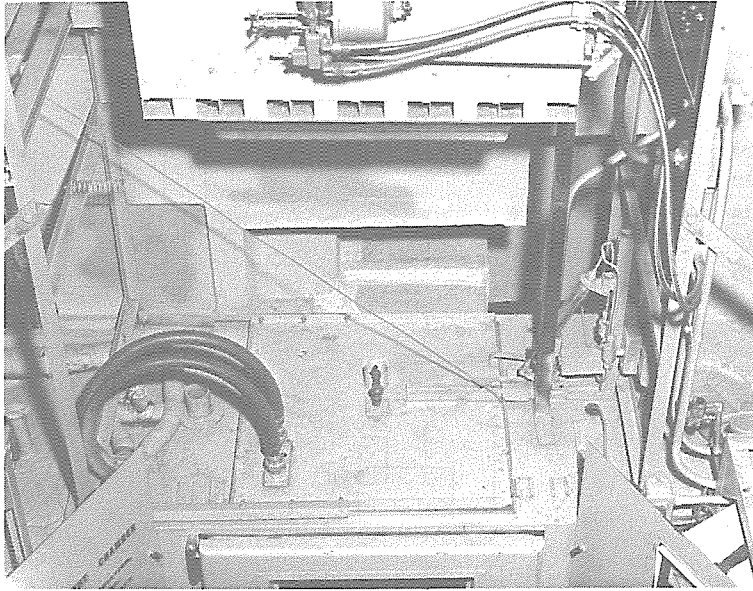


Figure 6—Cold-ceiling heat-sink unit simulates nighttime cooling in the test chamber. It operates for a specific time under preset conditions.

AIRFLOW CONTAMINATION CONTROL

Many tests conducted in the test chamber produce contamination, debris, or smoke which must be removed during testing. For instance, tests which ignite and burn a fuel sample create smoke and ash. All such contaminants, if circulated through the test chamber system, will alter the environmental conditions established for the test; create smudge; subject test chamber components to corrosion, pitting, nicks; and in extreme cases may even alter the operating characteristics of the components.

To reduce such contamination, an electro-static precipitator was installed in the test chamber main loop downstream of the blower. And a standard fibre glass filter was installed in the test chamber, just upstream of the work area, to collect any debris which may be produced by any of the control components.

Leakage of contamination through openings in the test chamber is eliminated by the careful sealing of all plumbing accommodation openings where pipes pass through the test chamber system walls, and by using rotating seals on the blower pulley shafts in both loops of the test chamber. This sealing procedure also reduces the chance for infiltration which could cause loss of control of a test in progress.

RECOMMENDATIONS

On the basis of experience in designing, modifying, and operating the test chamber, I offer these recommendations to those intent on developing a similar facility:

- Consider carefully the operating ranges of the test chamber and the size of the work area required. These factors determine the overall size of the chamber. A work area is only a small part of the unit (*fig. 7*). Boundary layer separation, inadequate mixing, excessive turbulence, and other harmful factors can invalidate the results of experiments if they are not eliminated or kept under control by adequate engineering design.

- Reduce conduction heat loss to a negligible level by using high-quality insulation. By so doing, heating and cooling calculations need only consider applied loads and environmental infiltration (such as air leakage through the work area). Applied loads include solar radiation, lights, heat produced by combustion of fuel samples, or any external device or process that would add heat to the test chamber system. Infiltration can be eliminated at openings by sealing the plumbing accommodations and using rotating seals on the blower pulley shafts. And it can be effectively reduced by limiting the number of times the access door to the work area is opened per hour.

- Add moisture by using a dry-steam producing unit to inject the required moisture, as vapor is more readily mixed in the airflow. Humidity control in the test chamber is the most difficult design problem to be overcome. The removal of moisture is, however, a more difficult task than adding moisture. The design humidity ranges required will govern the equipment used when low dewpoints are called for in testing.

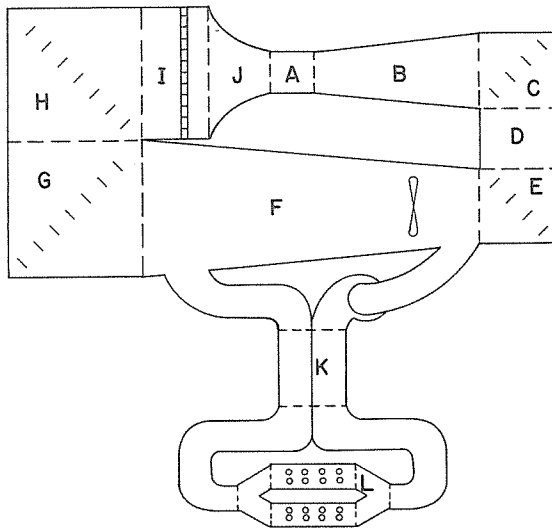
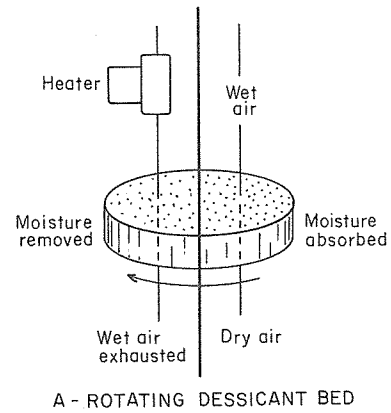


Figure 7—Components of the test chamber's low-turbulent, low-speed unit: A—10- by 10-inch test section; B—divergence area, 10° included angle; C—corner with vanes; D—settling cylinder, length = 0.8 diameter; E—corner with vanes; F—divergence area, 10° included angle; G—corner with vanes; H—corner with vanes; I—settling chamber, length = 1.5 diameter; J—contraction cone, ratio 10 to 1, length = 1.5 diameter; K—air-to-air heat exchanger; L—dehumidifying coils.

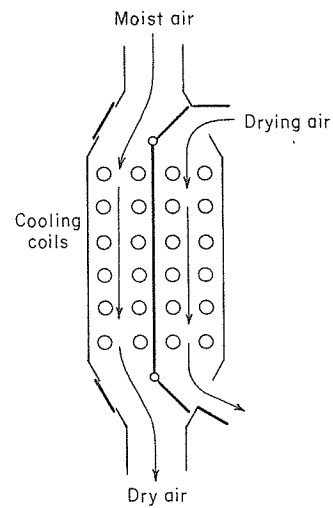
- Use high quality equipment to provide acceptable data when testing fuels in a laboratory. Air may be dried in a number of ways, the most common of which are refrigeration and desiccant drying; both methods have advantages and disadvantages.

- Use special equipment to reach low dewpoints if a desiccant is applied. Desiccant drying will control airflow moisture content from 10 percent relative humidity at 50°F. to 75 percent relative humidity at 10°F. without special equipment. If a desiccant dehumidifier is used to go below the limits, special desiccants must be used, and these require high temperatures for reactivation.

- Design the refrigeration dehumidifiers with a reliable defrosting system. Refrigeration dehumidifiers provide good moisture reduction and removal, but they produce ice. And ice presents a number of problems. The test chamber in use at Riverside, California, uses room air drawn over the dehumidifier coils by a blower, but test chambers designed for use in colder climates or in laboratories



A - ROTATING DESSICANT BED



B - REFRIGERATION COILS

Figure 8—Two types of dehumidifiers can be used in the test chamber: A—desiccant; and B—refrigeration. The refrigeration type is especially suitable in cold climates. Heaters can be installed in the intake ducts.

without air conditioning, an auxiliary heater may be installed at the room-air entry flapper valve (*fig. 8*). In either dehumidifying system, reduction of the relative humidity below the 10 percent level requires additional effort on the part of the test chamber in a logarithmic ratio; that is, each degree of humidity reduction below 10 percent squares the load requirements for accomplishment.

- Follow special precautions in creating a laminar, non-turbulent flow in the test section if straight or square ducting is to be used in the fabrication of a test chamber.

NOTES

¹Pope, Allen, and John J. Harper. *Low speed wind tunnel testing*. New York: John Wiley & Sons, Inc. p. 19, 36, 37. 1966.

²Gorlin, S. M., and L. L. Sibzinger. *Wind tunnels and their instrumentation*. Wash., D. C.: National Science Foundation. p. 38-42. 1966.

³American Society of Heating, Refrigerating, and Air-Conditioning Engineers. *Heating ventilating air-conditioning guide*. Baltimore: Waverly Press, Inc. p. 609-610. 1960.

⁴Dryomatic. *Dry conditioning bulletin No. 103*. Alexandria, Va.: Dryomatic. p. 2. 1965.

⁵Trade names and commercial products or enterprises are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

The Author

CLIFFORD J. AUVIL is an engineering technician with the Station's mass fire systems research unit, headquartered at the Forest Fire Laboratory, Riverside, California. He earned an A.A. degree in chemistry at Chaffey College (1951), and has been a member of the Station staff since 1964.



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