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The Transport of Food in I.S.O.* Containers

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Until recently, methods of handling export foodstuffs in ships have evolved slowly from those used in the days of sailing vessels. Many problems still exist, ranging from the multi-handling of some foods to the existence of unsuitable environmental conditions during transport. At present, an attempt is being made to sweep aside many of these problems by instituting the carriage of foods in standardized containers. However, containerization is not without its own problems. It is the purpose of this paper firstly to enumerate those problems that the use of containers has eliminated, then to discuss those which it has introduced, to give solutions to some of these, and to indicate where further research is needed. Most of the work on containers carried out by this Division over the past two years has been at the request of, and in cooperation with, Overseas Containers Australia Limited and Trans-Ocean Containers Pty. Ltd.

Traditional Practices

Normally, foods for export are produced some distance from a shipping port. They are packaged, transported by rail or road to a port, loaded into a ship, and sent on their way. To illustrate the multiplicity of handlings involved, the following procedure used for canned fruit is a typical example. Omitting the production of the fruit and transport to the cannery, the fruit rolls off the production line in cans which are then automatically cartoned. Each carton is stacked on a pallet, which is taken to the rail siding where the cartons are stacked in a rail van. When the van arrives at the shipping port the cartons are unloaded and restacked on trays, which are lifted into the ship. The cartons are then taken off the trays and restacked in the ship's hold. After the sea voyage the above procedure is reversed, the final unstacking being at the distributor's warehouse; after as many as four more stackings and unstackings the goods are finally displayed by the retailer for sale. This makes a total of eight to twelve stackings and a similar number of unstackings. This is time-consuming and consequently expensive; in addition it necessitates a rugged carton.

Frozen meat and live fruits are two examples of foods that are sensitive to carrying conditions. Meat is loaded into insulated rail vans and then takes as long as 30 hours to reach the ship's side. Here it may be kept without refrigeration for some time before it is hand loaded into the freezer hold or lockers. During these procedures there is a risk that the meat will not remain in the hard frozen condition, in which case it cannot be exported.

Some fresh fruits are particularly sensitive to temperature. They are usually packed in boxes or cartons and sent by rail in ice bunker wagons if the carrying temperature needs to be 32°F or a little higher. They are then stacked in large stows, usually in a temperature-controlled hold equipped with forced ventilation. Self heating in the fruit can cause trouble, particularly in large stows or where there is inadequate air penetration of the stow. This happens in many ships.

Container Transport System

The proposed container service is a complete break with traditional shipping arrangements. The basic system provides a regular door-to-

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* International Standardization Organization.

door transport service. Packaged foods are loaded either directly or on pallets into the container, the doors are sealed, the container is then transported by land, sea, and land to the consignee where the doors are opened and the contents discharged. This is the ideal system and applies in many cases; however, should the shipper wish to ship only a portion of a container load, the contents are unloaded at the container depot and restacked into a container with another consignee's load to make a full container, which then is delivered to the ship. After discharge from the ship the load is broken down and the various portions are sent to their consignees.

In general, foods not requiring refrigeration are shipped in uninsulated containers. Furthermore, with a few exceptions, normally refrigerated foods are not refrigerated while being transported in insulated containers over land. Their containers are merely used as insulated boxes. The conditions under which this can be done are discussed later. As soon as an insulated container arrives at the container terminal, and also whilst in the ship, it is connected to a supply of air at the correct temperature.

The turn-around time of the ship in port is nominally 36 hours and sailing times to Tilbury are 30 days from Sydney, 26½ days from Melbourne, and 22½ days from Fremantle.

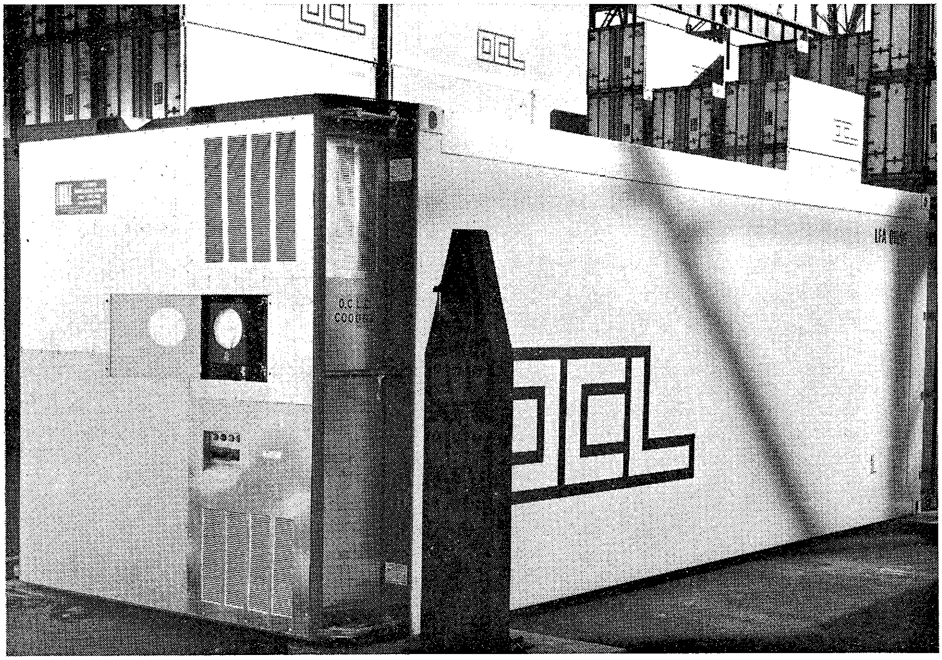

Fig. 1.—Clip-on refrigeration unit installed on container.

I.S.O. Containers

The containers to be used on Australian shipping routes conform to recommendation R668* of the International Standardization Organization. Although this allows for a range of sizes, the 20 ft × 8 ft × 8 ft container will clearly become the industry standard, with slowly growing use of the 40 ft × 8 ft × 8 ft container. All work reported in this paper has been carried out on the 20 ft × 8 ft × 8 ft container which will be the one referred to from here on. There is an uninsulated and

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* ISO R668 Dimensions and Ratings of Freight Containers.

an insulated version of this container; they have the same overall dimensions but the former has internal dimensions 19 ft $4\frac{1}{2}$ in. ×7 ft $7\frac{1}{2}$ in.×7 ft 3 in. whereas the latter varies from maker to maker but has a minimum size of 18 ft 7 in.×7 ft 4 in.×6 ft 10 in.

Figure 1 shows a typical container with clip-on refrigeration unit installed. Figure 2 is a sectional drawing of an insulated container showing an attached clip-on unit. The insulated container may be used simply as an insulated box, in which case no clip-on unit is used and insulating plugs are fitted to the two 10-in. air ducts. The clip-on units vary, but typical performance figures would be:

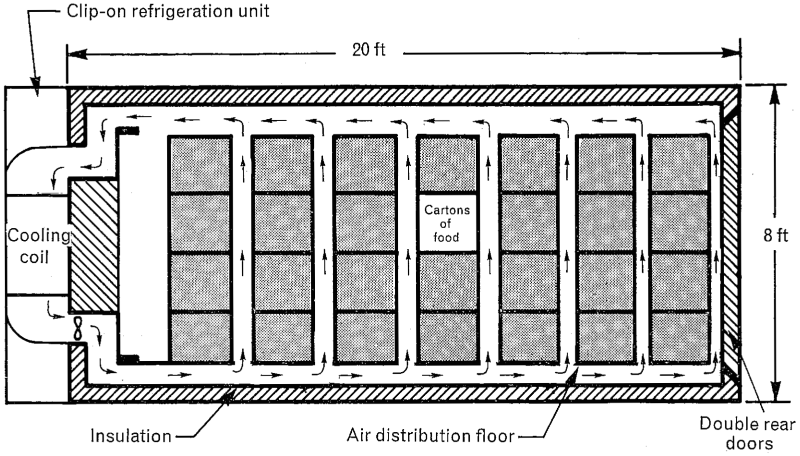

Fig. 2.—Section of insulated container showing circulation of cold air around stacked cartons.

Air delivery 1100 ft^3/min at $1\frac{1}{4}$ in. water gauge (W.G.);

Max. heat removal 7500 Btu/hr at 100°F ambient temperature and controlled temperature of 0°F.

The container door seals are designed to have a leakage in the range 3–5 ft^3/min at $1\frac{1}{4}$ in. W.G. Circulation is designed to provide the cargo with a jacket of air at controlled temperature. The direction of air flow is indicated in Figure 2; air flows from the lower 10-in. duct, along the floor slats, up the back and sides, thence over the top to the exit duct. Spreaders are provided at the two ducts to improve the uniformity of distribution. Except with heat-producing cargo, e.g. fresh fruit, air need not flow between the food packages.

Thermal Performance of Insulated Containers

The shipping companies will not accept containers having heat leakage rates greater than 50 Btu/hr/degF at a mean insulation temperature of 50°F (e.g. 0°F inside and 100°F outside). This is quite a stringent requirement since, for a mean surface area of 700 sq ft, the thermal conductance can be no greater than 0·07 Btu/hr/degF/ft^2. This calls for a minimum of 3 in. of foamed polyurethane or its equivalent. Several manufacturers have used additional insulation on the floor, mainly to overcome the increased heat flow caused by structural members.

Tests carried out by the Division have shown that typical containers have heat leakages in the range 35–45 Btu/hr/degF. The values obtained do not vary much with the mean temperature of the insulation over the range 30–90°F. Three different methods were used, depending on the mean temperature of the insulation:

- Electrical heaters were used to supply a known amount of heat per unit time to the container.
- Ice was placed in the container and its melting rate determined.
- Liquid nitrogen was sprayed into the container and its consumption measured.

In all cases the temperature of the container was allowed to come to equilibrium (about 36 hr) and the mean temperature difference between the inside and outside surfaces was measured using 46 thermocouples on each.

Main Advantages of Containers

The first and most obvious improvement brought about by the use of containers is a tremendous reduction in handling of goods. Foods and food packages arrive in better condition than with conventional handling, rain damage is eliminated, and the opportunity for pilfering is considerably reduced. In addition, refrigerated cargo is not exposed to ambient conditions on the wharf.

Secondly, the increased speed of the whole system means that there is less time for the deterioration of the foods; consequently they arrive at their destination fresher and with increased shelf-life. Thirdly, the separation of cargoes of different types reduces the chance of cross-tainting between foods.

The guarantee of a regular service is a distinct improvement since it permits long-term planning of production schedules. In addition, the overall door-to-door costs of transportation are considerably reduced.

Disadvantages of Containers

Standardization always brings with it the difficulty of handling non-standard items. The shipping of less than a container load is more expensive in proportion because of the increased handling costs. However, it may still be cheaper than conventional shipping methods.

Because of the fixed internal dimensions of the container some existing well-established package sizes will stack inefficiently. It is certain that the advent of containers will lead to a considerable upheaval in the packaging industry.

Problems with Specific Foods

Many foods present problems of one kind or another in conventional ships. In the majority of cases these problems are reduced or avoided altogether in containers. Three types of cargoes that create difficulties on conventional ships as well as in containers have been studied by this Division:

- Frozen boneless beef;
- Live fruits;
- Canned foods.

Frozen Cartoned Boneless Beef

Beef is exported in considerable quantities in 60-lb cartons. The Department of Primary Industry requires* that the meat be 'sufficiently frozen' at the time of loading onto the ship. No specific temperature is mentioned in the regulations but measurements have shown that meat up to 24°F is acceptable.

Meat is normally supplied in the temperature range 0–10°F at the abattoir cold store. Experiments and calculations have been carried out to determine whether it is possible to use unrefrigerated, insulated containers to transport the beef from the abattoir to the container terminal where refrigeration is available. Clearly the overall transport costs are reduced if the number of clip-on units needed is reduced.

Several unrefrigerated trial runs by rail and road were made from the Queensland border area to Sydney. Computer programmes were set up to solve the heat flow equations and it was found that when allowance was made for the natural convection that takes place in the container, the computed temperatures matched the experimental ones very well indeed. This led to the possibility of predicting the temperature rises under a wide variety of external conditions, and showed that refrigeration is unnecessary in most circumstances. In making these predictions the maximum allowable meat temperature was taken to be 20°F.

Since each top corner of the stow receives heat from the top, from one end, and from one side, it heats up more quickly than any other part of the stow. Consequently the top corners are the danger zones with this type of cargo. By accepting the criterion that the meat at the top corner 1 in. in from each side shall not exceed 20°F, a considerable safety margin is allowed. In addition, as soon as the refrigeration system is connected, these are the very positions at which cooling is fastest, so that by the time the container is due to be lifted into the ship all of the meat will be well below 20°F.

The results of this work are summarized in Table 1, which shows the number of hours for which a full container load of 60-lb cartons of frozen boneless beef can be left unrefrigerated before its corners reach 20°F,

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* Commonwealth of Australia Exports (Meat) Regulations 1961–1966.

as a function of the ambient temperature and the temperature of the meat when the container doors are closed at the abattoir. This table applies to a container that just meets the specification of 50 Btu/hr/degF for the heat leakage rate. Most containers have an additional safety factor of at least 10%.

Table 1
Maximum Safe Transport Time (Hr) for Frozen Beef

Beef Temperature at Door Closure (°F)†	Ambient Temperature (°F)								
	60	65	70	75	80	85	90	95	100
−10	*	*	*	*	*	*	80	71	62
−8	*	*	*	*	*	82	71	62	53
−6	*	*	*	*	82	71	61	52	46
−4	*	*	*	83	71	60	51	44	39
−2	*	*	85	71	60	50	42	37	33
0	*	86	71	58	49	41	35	31	27
2	87	71	57	47	39	33	28	24	22
4	71	55	44	37	31	26	22	20	17
6	53	42	34	28	23	20	17	15	12
8	41	31	24	20	17	14	12	10	9
10	27	21	17	14	11	10	8	8	7
12	17	13	11	9	8	6	6	5	4
14	10	8	6	5	4	4	3	3	3

* Greater than 100 hr.

†Temperatures apply to 1 in. below the surface of the beef in the outer corners of the top four corner cartons in a container fully loaded with 60-lb cartons of frozen boneless beef. They are to be used only as a guide, since the actual values achieved depend markedly on the precise stacking pattern used.

It can be seen that on rare occasions only is a clip-on unit needed, mainly for long journeys in mid summer. Since the container companies now have charts similar to Table 1 they can estimate the number of clip-on units needed, and supply them as conditions demand.

Similar tables may be computed for other products provided the following information is available: the thermal conductivity, density, and specific heat of the product and package, together with the air flow in the container. This latter depends on the stacking pattern used and the shape of the package. Understandably, such a table must be extensively tested by comparison with the results of experiments on container loads of the particular product before great reliance can be placed on it.

Live Fruits

The problems associated with live fruits (and to a certain extent vegetables) are quite different from those of meat. The carriage temperature is usually in the range 32–35°F and allowance must be made for the removal of the heat of respiration.

It has been recent practice in conventional ships to use dunnage with cartons of fruit to ensure an adequate flow of air past the sides of the cartons. In the hold of a ship having the air flowing vertically upwards past the largest carton side, and using $\frac{1}{2}$-in. dunnage, it is possible to hold the temperature of the fruit in the centre of a carton at only a few degrees above the required carrying temperature. This is more difficult with downwards air flow.* In a container, where the air flow is upwards and is well distributed over the floor, and where the stack height is limited to about 7 ft, it is likely that the amount (and hence cost) of dunnage can be reduced. Computations have shown that $\frac{1}{2}$ in. is still optimum but that the flow at the rear of the container is very susceptible to changes in carton spacing at the front. Since a small amount of movement of the cargo is hard to prevent when dunnage is used, measurements were made on stacks without dunnage.

A considerable amount of air was found to flow up the gaps between cartons even in a supposedly tight stow and this air adequately removed heat from the fruit. Again, the air flow depends on the size of the carton and the stacking pattern and is greatly influenced by large gaps which occur because of the poor fit of some carton sizes in a container.

Canned Foods

In conventional ships, apart from the handling difficulties mentioned earlier, the only major difficulty with canned foods is condensation. This causes dampness of the carton material, rusting of cans, and mould growth on cans and labels. The food is not damaged but the product may become unsalable or require extensive relabelling. The

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* Foster, R. W. (1967).—The use of ships as precoolers for fruit. *N.Z. Jl Sci.* **10**, 896–914.

cause of condensation is well known: water vapour condensing on metal that is cooler than the dew-point temperature of the air surrounding it.* The chief sources of this water vapour are outside air, other cargo, and packaging material around the cans.

In the uninsulated containers in which canned goods are carried, except for mixed loads the first two sources of water vapour are eliminated; the third can be a problem. Condensation may occur if cans are packaged in moisture-containing material, e.g. fibreboard. If, for example, warm cartons of cans are loaded into a cold container, condensation occurs on the inside of the roof of the container and drips onto the cartons. Condensation can also occur on the roof if the same container is left in an exposed position on a cold night. Also, if a container-load of cartoned canned food is left in the sun on a hot day, moisture will migrate from the warm carton material at the top of the container and condense on the cooler cans below. This problem can be overcome by the use of packaging materials that contain little or no water, or by the use of plastic wraps.

Unsolved Problems

The major problems still to be solved concern packaging and stacking. Foods that can be transported in uninsulated containers may be stacked as tightly as possible. Optimum package size then depends on the dimensions of the package contents and the container and, to a certain extent, on the thickness of the packaging material. In certain high-density packs the full height of the container may not be usable because of the maximum weight limit on the load of $18\frac{1}{3}$ tons.

In insulated containers the load limit is $17\frac{1}{2}$ tons and the same considerations apply, except for foods needing ventilation. Tight stacking or self-locking stacks are essential to eliminate movement of the stow during transport on land. However, deliberate gaps may be essential in some cases to prevent overheating. It may be possible to satisfy these conflicting requirements with some special form of package, e.g. well-ventilated cartons or self-spacing cartons. Because of the variability of air flow in any given stacking pattern, precise computations of heat removal rates are not possible. Consequently the virtues of any proposed system of overcoming the self-heating problem can only be assessed by extensive experimental programmes.

The reduction in handling of the packages and the maximum stack height suggest the possibility of using weaker and therefore cheaper packages. This reduction in cost could be partly absorbed in treating the packaging material to prevent the release of water vapour from it. This would solve the condensation problem.

One type of condensation that is difficult to prevent while current packaging methods are used has not been mentioned so far. Canned goods shipped during the Australian winter arrive in Britain during the British summer. The cans are cold and when the container is opened in Britain on a warm humid day condensation on the cans begins soon after the doors are opened. Waterproof packaging materials can, to a large extent, alleviate this problem.

Conclusions

Overall, the transport of food in containers shows promise of presenting a higher-quality Australian product on overseas markets. It has solved a large number of expensive problems and has created no insuperable new ones. Much work remains to be done, particularly in packaging, before the system can achieve its full potential, but it seems clear that within the next few years containers will become the preferred method for the transport of foods overseas.

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* Middlehurst, J., and Kefford, J. F. (1968).—Condensation in cargoes of canned foods. CSIRO Aust. Div. Fd Preserv. tech. Pap. No. 34.

Humidity and Moisture Measurement

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Water vapour is always present in our surroundings but unlike the fixed proportions of other components of air such as oxygen, nitrogen, or rare gases, the concentration can vary over a wide range. Most materials and living organisms continuously adjust their moisture contents by sorbing and desorbing water, and determining and controlling this water is important in many industrial processes. Food technology, in particular, is faced with both the prevention of moisture exchanges, e.g. in packaging and storage of foods, and controlled removal of water to reduce weight and extend storage life, e.g. in dehydration and freeze drying.

Water Vapour in Air

The amount of water vapour in air can be specified either by the water content or by the vapour pressure exerted by it.

Absolute humidity is the mass of water vapour contained in a unit volume of air (g/m^3, i.e. gramme per cubic metre, or p.p.m., i.e. parts per million) and is used mainly in diffusion studies.

Specific humidity is the mass of water vapour per unit mass of moist air (lb H_2O/lb air).

Mixing ratio is the mass of water vapour per unit mass of *dry* air (lb H_2O/lb air).

The unit weight of dry air is a very useful quantity in psychrometric calculations, as it remains constant in processes of cooling, heating, dehydration, and humidification where temperature, vapour pressure, and humidity variations occur simultaneously. Thus the mixing ratio is used widely in air conditioning, refrigeration, and dehydration engineering. Numerically the difference between specific humidity and the mixing ratio is negligible for most practical purposes.

Relative humidity (R.H.) is the ratio of water vapour pressure in air to saturation vapour pressure at the same temperature, expressed as a percentage:

$$\text{R.H.} = (p/p_0)_T \times 100\%$$

where p = water vapour pressure of air at temperature T,

p_0 = saturation vapour pressure at the same temperature T.

R.H. is very important in considerations of human comfort and is used in meteorology, air conditioning, and refrigeration.

Saturation water vapour pressure is the vapour pressure of water in equilibrium with a free water surface. Alternatively it can be defined as the pressure exerted by the maximum amount of water that can be contained in the air at a given temperature. Since the saturation vapour pressure increases rapidly as the air temperature rises, R.H. alone does not specify the *amount* of water vapour in the air unless temperature is also stated.

Dew point is the temperature at which saturation occurs when air is cooled without change in water content. This is also a very useful parameter, as it specifies temperature and 100% R.H. simultaneously, and hence saturation vapour pressure or saturation water content as well. Changes in air temperature above the dew point do not affect the water content, but cooling below the dew point removes moisture from the air by condensation on cooler surfaces. Thus some of the obvious practical uses of dew point are where evaporation is to be induced, as in dehydration, or where condensation is to be prevented, as in the storage and transport of goods.

Condensation will occur on goods in a store or railway car if the temperature of the goods drops below the dew point of the ambient air, as frequently happens at night. The obvious and cheapest method of preventing water damage such as rusting of cans or wetting of bulk commodities is to ventilate with drier and warmer air to evaporate the condensed water as soon as possible. However, it is not appreciated sufficiently that indiscriminate ventilation may aggravate the problem.

If, for example, a cold night (45°F) is followed by a sunny morning with a temperature of 69°F and 60% R.H., and ventilation is started before the goods have warmed up to at least 55°F, no drying can be expected (Fig. 1). On the contrary, every pound of air at 69°F and 60% R.H. (point A) coming into contact with a surface of 45°F (point C) will deposit 20 grains of water. This is the difference in moisture content between air with a dew point B of 55°F (69°F, 60% R.H.) and air with a dew point C (45°F, 100% R.H.), equivalent in moisture content to 69°F, 41% R.H. Thus, immediate ventilation with air at 69°F can be carried out only if its R.H. is below 41% (point D).

Similar conditions might be encountered in railway vans, trucks, or ships passing through cold and warm districts. The example illustrates that R.H. is an unreliable guide for assessing drying or humidifying conditions when simultaneous but unequal temperature variations of the air and goods occur. The dew point is the safest criterion in such cases.

Measurement of Humidity

Just as there are several ways of defining the psychrometric state of the atmosphere, there are also many methods of measurement. Although a variety of instruments, designed for particular conditions, is available, there is no hygrometer suitable for all purposes over the full range of humidities and temperatures.

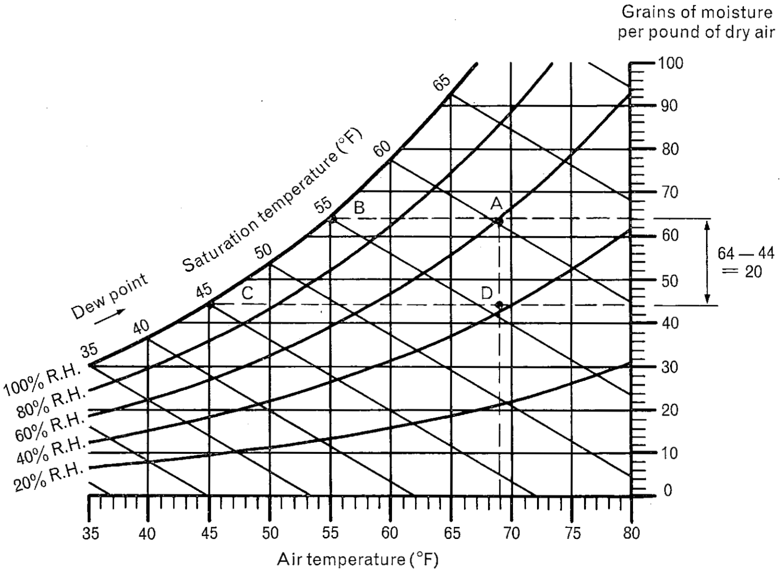

Fig. 1.—Psychrometric chart.

The aims of this survey are to describe the advantages and limitations of some of the instruments likely to be useful in the food industry and research, and to provide some background information to assist in the choice of the most suitable instruments and methods.

Coulometric Hygrometer[1]

Low water concentrations in gas cylinders, refrigerants, furnaces, and high-temperature dryers can be determined by coulometric measurements. The gas is passed at a constant flow rate through an electrolysis cell where all water is absorbed by partially hydrated phosphorus pentoxide. The resulting current in the cell is directly related by Faraday's law to the concentration of water in the gas stream (Keidel 1959). Response time claimed for 63% of full step change indication is 30 sec. The range covers

1–1000 p.p.m. and can be extended to 1–20,000 p.p.m. The accuracy is ±5% of the full scale on any range.

Piezoelectric Humidity Sensor[2]

This instrument, described by Gjessing *et al.* (1968), is based on the relationship between the mass and oscillation frequency of a quartz crystal. Two crystal oscillators are paired to give a beat frequency almost independent of temperature. One crystal is insensitive to humidity, the other is coated with a hygroscopic film, which can sorb and desorb moisture. The mass and oscillation frequency of the coated crystal change with changes in ambient conditions, and the resulting variation in beat frequency is measured. Typical sensitivity quoted is 10 Hz per 1% R.H. change, with a total range of 50 Hz, for temperatures −40°C to +25°C.

A commercial instrument of this type, having five ranges from 5 to 25,000 p.p.m. water vapour by volume, is mentioned in a review by Ewing (1968).

Dew-point Measurement

Air is cooled without change in water content until saturation is reached. The temperature at which condensation first appears on a cooled mirror surface is measured, and from the dew-point temperature, the vapour pressure and R.H. of the air at any other temperature can be derived. The principle of the dew-point meter is theoretically simple and straightforward, and was first described nearly 140 years ago. Many improved versions have been designed and produced since then, but all suffered from three main drawbacks: firstly, a degree of uncertainty in precise visual recognition of the point at which dew appeared and disappeared, which made the measurements dependent on the skill of the observer; secondly, difficulties in accurate temperature determination at the moment of dew formation; and thirdly, maintenance of a contamination-free surface.

Modern automatic instruments (Gerthsen, Gilsing, and van Tol 1960) have overcome most difficulties. They incorporate thermoelectric cooling of the mirror, photoelectric detection of the onset of dew deposition, and automatic adjustment of the mirror temperature. A beam of light is reflected from the cooled mirror surface onto a photoresistor. Dew formation causes misting of the mirror and a change from specular to diffuse reflection so that less light reaches the photoresistor. The decrease in the photo-current controlling the thermoelectric element causes less cooling. When the system reaches equilibrium, the temperature of the mirror is equal to the dew point, and a constant, very thin layer of dew is maintained on the mirror surface. The operation is automatic and suitable for continuous recording.

The error in temperature indication is claimed to be within ±0·25°C, which in air at 25°C corresponds to an uncertainty interval of 1·5% at 50% R.H. and 2·5% at 80% R.H. A clean mirror is essential, otherwise false readings are obtained. Several major instrument companies produce automatic thermoelectric dew-point meters. With refinements in construction and electronic circuitry there is continuous improvement in sensitivity and performance of new models.

Related to the dew-point hygrometer is an instrument based on the behaviour of a saturated lithium chloride solution. Saturated salt solutions have a characteristic vapour pressure which is lower than pure water and depends only on the nature of the salt and the temperature. When placed in an atmosphere of a higher R.H. they absorb water and become diluted, whereas in drier surroundings water evaporates until the vapour pressure of the solution equals that of the air. Equilibration of vapour pressure can be achieved also by manipulating the temperature while keeping the concentration of the solution at saturation point.

This principle is used in the Dewcel[3] and Dewprobe[4], which consist of a thermometer covered by woven glass tape impregnated with a saturated lithium chloride solution and wound with a bifilar coil of two wire electrodes. A flow of alternating current between the coil wires heats the solution and causes some evaporation of water. This increases the resistance between the wires, which reduces the current and heat input so that the solution cools down again. Hence vapour pressure is lowered, and the solution absorbs water from the atmosphere and is diluted again. Thus the device is self-regulating and the solution finally attains a temperature corresponding to a constant resistance, which means that no further water exchange with the surrounding atmosphere takes place, i.e. the vapour pressures of the solution and ambient air are equal. The indication of the thermometer inside the coil gives the equilibrium temperature, from which the dew point or R.H. can be derived. This type of dew-point hygrometer functions best in still air, because air movements promote heat loss from the solution, lowering the equilibrium temperature and changing the calibration. The operating range of the instrument is temperature-dependent and is limited by the equilibrium R.H. of the saturated lithium chloride solution. At 20°C the range is from 100% to 12% R.H. and at 90°C from 34% to 12% R.H.

Electric Hygrometers

Instruments of this class use the variation of resistance, capacitance, or some other electrical parameter of a sensor with changing water sorption or desorption. The sensing element consists of metal or carbon electrodes attached to an insulating base of glass, porcelain, synthetic fibre, or plastic. A thin layer of a dilute solution of ionic salts or acids acts as the humidity-sensing component as it equilibrates with the ambient atmosphere by sorbing or desorbing water and varying in conductivity or capacitance with changing concentration. The fibres of the insulating base may be impregnated with the solution or part of the surface may be coated with it, either directly or mixed with a binder or a gel to improve retention.

Electrolytic conduction hygrometers[5].—The common characteristics of different makes of electrolytic conduction hygrometers have been described by Wexler (1957, 1964). Advantages of these elements are: small size, high sensitivity, fast response, and convenient operation. Since the response is in the form of electrical resistance, current, or voltage, the output is easy to record, amplify, or use for remote control.

The main limitation is that these are empirical devices which require calibration. They are temperature-dependent, so that if the temperature is varying, several calibrations are necessary or temperature correction coefficients must be applied. They also suffer to a varying degree from hysteresis, i.e. a difference in indication when the sensor approaches the measured value from a higher or lower humidity. Ageing, which shows up as a gradual deterioration in performance and an increase in resistance, is another problem. In addition exposure to saturated air, wetting, or contamination with ionic substances will shift the calibration and may ruin the sensor.

Some of the limitations mentioned above are claimed to have been overcome in an instrument[6] using a polystyrene element with an electrolytically conducting surface layer incorporated in the plastic surface. By this means stability of calibration has been achieved and it is claimed that the element will withstand condensation and brief immersion in water. The operating range is 40–90% R.H., accuracy ±3%, and the temperature coefficient 0·2% R.H. per degF. However, at 85% and above, the elements were found to have low sensitivity, high hysteresis, and an extremely slow response.

Capacitance sensor[7].—Another stable and permanent type of sensor available in Australia relies on capacitance variation and has four interchangeable elements for ranges of 0–2%, 0–5%, 0–40%, and 0–99% R.H.

A definite advantage of the small sensors is the ease with which they can be checked without elaborate testing facilities. Their accuracy, reproducibility of indication, and response time can be determined by placing them in atmospheres of fixed R.H. provided by saturated salt solutions.

Wet- and Dry-bulb Hygrometer

Undoubtedly this is the most used instrument in industry, research, and meteorology, despite its somewhat unsatisfactory theoretical background. The R.H. is calculated by means of a semi-empirical formula from temperatures indicated by the wet- and dry-bulb thermometers. To avoid the need for solving a mathematical equation for each pair of readings, tables are available for R.H., water vapour pressure, and dew point for the dry- and wet-bulb temperatures in Centigrade degrees (German Meteorological Service 1955), and for dry-bulb and the difference between dry- and wet-bulb temperatures in Fahrenheit degrees (Marvin 1941; Zimmerman and Lavine 1945). The accuracy obtainable depends on two factors: the working formula and the temperature measurements. As the formula employs an empirical constant, valid for limited operating conditions, these conditions should be carefully maintained. They are:

Adequate ventilation—at least 10 ft/sec. The wet-bulb indication depends on the rate of evaporative cooling, which is related to air circulation around the wick. For commercial aspirated instruments such as the Assmann[8] and whirling[9] psychrometers, proper ventilation is 'built in' by the designers, but where separate thermometers are set up in restricted areas this tends to be overlooked.

Protection from radiation. The formula is derived for adiabatic evaporative cooling, therefore heat exchange with the surroundings must be avoided and the instrument should not be operated in sunlight, near a light bulb, or in the vicinity of a large surface much colder or warmer than the ambient air.

Maintenance of a clean wick. Contamination of the wick can cause erratic readings, so it should be wetted only with distilled water. In dusty or contaminated atmospheres the wick should frequently be replaced, or boiled out. With careful operation using accurate thermometers capable of being read to 0·1°C an accuracy of ±1% R.H. is possible.

Wet and Dry Thermocouples

When thermocouples replace the thermometers, the system can be considerably reduced in size and used for remote indication or control. An additional advantage is the less stringent requirement for ventilation and shielding, because the heat capacity and area of the thermoelements are much smaller than those of mercury-in-glass thermometers. Tests at the National Physical Laboratory in Britain proved that readings obtained in still air with thermocouples made from 44 S.W.G. wires were only 2–3% higher than the true values obtained with proper ventilation.

An instrument using *thermistors*[10] in a compact instrument case with push-button ventilation and built-in reservoir for wick wetting is now commercially available. It provides temperature indication accurate to 0·2°C on three ranges: −10–20°C, 20–50°C, and 50–80°C. Additional advantages of this design are rapid response, due to small thermistor size, and very convenient operation.

Hair Hygrometer[8,9]

This instrument relies on the capillary water sorption of a strand of hair and the consequent change in length. In the present era of electronics and automation it may be regarded as relatively crude, but it is still widely used and is quite satisfactory for certain applications. The capillary absorption of water vapour by a substantial bundle of hair is a slow process and depends to some extent upon the amount of water already in the system. Accordingly, the response of hair hygrometers is slow (10–30 min) and there are marked hysteresis effects. The instruments should not be exposed to wide humidity and temperature fluctuations or to extremely dry or wet conditions. But for indicating or recording slow humidity variations at near-constant temperatures, e.g. in air conditioning systems, they can give excellent service if properly adjusted and maintained. The accuracy is 2–5% R.H. in the range 30–80% R.H. and 10–25°C. As hair has a negative temperature coefficient of expansion, instruments adjusted for a temperature of 20°C will read approx. 10% low at 40°C and 10% high at 0°C. Accordingly the instruments must be readjusted when operated at a temperature markedly different from the normal calibration temperature.

Water in Solids and Liquids

By close analogy with moisture content and R.H. of air, the water in solids or liquids can be specified either as a weight ratio or as a vapour pressure ratio.

Moisture content is the amount of water contained in 100 g material, either wet or dry (g H_2O/100 g total weight or g H_2O/100 g dry solids), and is widely used by chemists and food processors to designate the composition or state of dehydration or hydration of a product.

Water activity is the ratio of vapour pressure exerted by the water contained in the material to the vapour pressure of a free water surface at the same temperature, and is mainly used by biologists and bacteriologists.

$$a_w = (p/p_0)_T,$$

where p = water vapour pressure of the sample at temperature T,

p_0 = saturation vapour pressure at the same temperature.

The same ratio expressed as a percentage is called *equilibrium relative humidity* (E.R.H.):

$$\text{E.R.H.} = (p/p_0)_T \times 100\%$$

and is equal to the R.H. of the surrounding atmosphere at which the material will neither gain nor lose water. The E.R.H. of a stored product will asymptotically approach the R.H. of the storage atmosphere. Similarly, during dehydration, the product can be dried only to a certain E.R.H., which is determined by the R.H. and temperature, or the dew point of the drying air. As the E.R.H. also determines whether the material will support or inhibit bacterial or fungal growth, E.R.H. data provide more direct information relevant to processing, packaging, and storage of foods than does moisture content.

The correlation between the water content of a material and the vapour pressure exerted by it, usually given as a plot of E.R.H. against moisture content at a given temperature, is called the *sorption isotherm* (or *equilibrium moisture curve*) and represents valuable information about the product and its environmental requirements. Quantitative predictions can be made of the water gain or loss that will occur under particular storage conditions. The shape of the sorption isotherm also reveals something of the nature of the bonding forces between the water and the surface, i.e. the relative amounts of water held by capillary forces and sorbed in a single or multilayer array on the surface.

The sorption isotherms are also helpful in assessing the compatibility of different components packaged together, as in dehydrated soups, cake mixes, or breakfast cereals with added dried fruits, etc. Moisture migration will occur not necessarily from the product with the higher water content, but along a vapour pressure gradient from the product with higher E.R.H. to the component with lower E.R.H.

The E.R.H. of a product in storage conditions, i.e. in its package or container, can conveniently be determined with a small plastic probe developed in the CSIRO Division of Food Preservation (Szulmayer 1968). The R.H. sensors are suitable for the range 10–95% R.H. and 0–30°C. They are not available commercially, but are easily constructed.

Measurement of Moisture

Moisture determinations in solids or liquids can be classified broadly into direct and indirect methods.

Direct Methods

In this group the weight loss of the sample is determined after the water has been removed by oven or infrared drying, or the moisture is condensed and trapped after evaporation and its volume measured as in entrainment distillation, or the water is determined in quantitative chemical reactions with specific reagents, as in the Karl Fischer titration. Detailed laboratory procedures are available for each of these methods (Association of Official Agricultural Chemists 1950; Royal Australian Chemical Institute 1952). Their advantages and limitations when applied to canned foods were discussed by Kefford (1955), and reviewed by Pande (1963) in more detail. With dehydrated or freeze-dried materials, apart from the accuracy and reproducibility of the method itself, there is always some error introduced through moisture pick-up during the preparation of the samples by mincing or grinding. The magnitude of this error is generally unknown and hard to determine, but it increases sharply with increasing dryness and hygroscopicity of the material.

Indirect Methods

These use the variation of some measurable property of the product as indication of water content, e.g. resistivity or dielectric constant. These electrical moisture meters require little skill in use, give instant indication, and can be adapted to surveying flow processes by means of continuous scanning, or repeated automatic sampling.

A survey by a worker of the Scientific Instruments Research Association (Geary 1963) listed 25 British-made moisture meters, of which seven are suitable for foodstuffs. German, American, and Australian instruments are also available. Space does not permit discussion of the construction or performance of all these instruments, so a few characteristics, common to all, will be described.

Electrical Conductivity Meters[11]

These instruments consist of a set of electrodes, a measuring circuit, and an indicating or recording device. A sample of the product is placed between the electrodes and provision is made for adequate contact. In some, the electrodes are in the form of prongs or needles that are inserted into the solid or the loose bulk material, but the cylindrical or box-like container is more usual.

The resistance measuring instruments have the advantage of relatively uncomplicated bridge circuits. The conductivity of the sample increases with increasing moisture content, but variable amounts of electrolytically conducting constituents or additives, e.g. sugars and salts or sulphite ions in sulphured dried fruits, interfere and will obviously affect the accuracy.

Moisture distribution in the sample should be uniform. As the current follows the path of lowest resistance, a single wet spot in the product can give false readings. Variations in packing density and contact resistance between electrodes and product should also be avoided, and the temperature of the samples should preferably be kept at 20–25°C. For large temperature variations a temperature correction must be applied.

Capacitance Moisture Meters

Instruments based on capacitance measurement rely on the large difference in dielectric constant between water and dry solids. They generally operate at audio or radio frequencies and their electrical circuits are accordingly more refined.

In several respects the capacitance measuring instruments have slight advantages over conductivity meters: small quantities of many electrolytes present in commercial products usually will have only a very small effect on the dielectric constant, whereas conductivity can be greatly increased; physical contact between test materials and electrodes is unnecessary. This not only eliminates a source of inaccuracy, but allows greater flexibility in electrode design, permitting easier adaptation to rapid sampling or continuous flow measurement.

Electrical moisture meters must be calibrated for each material. Variability within the product due to variety and maturity differences in crops, production differences between batches, or intrinsic inhomogeneity will affect the accuracy and reproducibility of measurements. This will occur even when the influence of electrode contact resistance and differences in packing density of loose materials can be eliminated.

Accuracies achieved, as quoted by British manufacturers, range from 0·1 to 5% moisture. It is understood that the high accuracies (below 0·5%) were obtained on very uniform and homogeneous materials in carefully controlled conditions.

Microwave Moisture Meters[12,13]

These instruments (Anon. 1964) consist of an ultra-high-frequency klystron generator, waveguides, a measuring head, attenuator and detector circuits, and recorder. The measuring head has a transmitter horn and a separate receiver horn which can be mounted on a conveyor belt so that the material to be measured flows in a uniform volume between them. Water molecules have two highly selective absorption bands in the microwave region, therefore the signal arriving in the receiver horn after passing through the product is attenuated in proportion to the amount of water present. The response is instantaneous and almost linear. The instrument can measure the total water content in a large volume of material, but requires previous calibration. It was developed for moisture determination in brick walls, masonry, and timber but was also found suitable for the measurement of moisture in oil pipelines, fertilizer conveyors, grain silos, and during flour milling. The accuracy claimed is ±0·25% for the range 5–25% wet weight, for temperatures between −10°C and +55°C. The instruments are particularly suitable for 'in line' moisture monitoring and control, but portable microwave moisture meters[13] are also available. A sample size of approximately 1 kg is desirable, but this depends on the moisture content.

Nucleonic Moisture Meters[13]

These consist of a radioactive emitter of fast neutrons and a slow neutron detector. The fast neutrons emitted from the radioactive source are scattered and slowed down by collisions with the light hydrogen nuclei present in the tested product, but their speed is not affected by collisions with nuclei of higher atomic weight. The response from the neutron detector is therefore a measure of the number of neutrons that have been slowed down and scattered back, and indicates the hydrogen content in unit volume of the sample. To obtain the weight per cent of moisture, which is required for most practical applications, the product density must be known. In materials with fluctuating density (e.g. soils) it can be measured simultaneously with moisture by means of a separate gamma ray detector. The quotient volume moisture/density is computed electronically, so that automatic compensation for density variation can be applied to moisture readout.

Separate radioisotopes are usually used as neutron and gamma emitters: radium–beryllium or ^{241}americium–beryllium, and ^{137}caesium respectively, with separate neutron and gamma detection systems.

However, the two emitters and two detectors may be combined in one probe and operated with a double scintillation counter together with a pulse shape discriminator and associated electronics for signal processing (Nagy and Razga 1966). The neutron moderation is not affected by temperature, pressure, pH, or chemical composition as such. However, hydrogen atoms in the sample from sources other than water molecules will act as neutron moderators and be counted as water, and this constitutes a serious limitation for organic materials.

Nuclear Magnetic Resonance

Nuclear magnetic resonance (N.M.R.) is based on the absorption of energy by a nucleus subjected simultaneously to a strong magnetic field and incident radiation. Hydrogen nuclei in water molecules have a pronounced resonance absorption at a specific value of magnetic field and radio-frequency, so the resonance amplitude of a signal is used as a measure of the water present. Furthermore, from the shape of the signal curve it is possible to distinguish between the bound water and water adsorbed on the surface. The measurements are rapid, non-destructive, and more precise than oven drying. The standard deviation reported is 0·06%, range 4–100%. However, the method is not absolute and requires calibration with samples of known water content. The hydrogen signals from protein, carbohydrates, and bound water are sufficiently different to avoid interference in high-resolution instruments (Miller and Kaslow 1963).

This is not so for the cheaper, low-resolution N.M.R. machines, where all single-proton nuclei contribute to the same observed signal and at present differentiation between the hydrogens contained in water, fats, and sugars is impossible. Other problems include: sample temperature, previous heat treatment, viscosity, and surface effects which influence the signal strength. In addition, where the water is strongly bound, low moisture contents are not detected (Andrews and Simmons 1967).

Conclusion

It is obvious that the last three types of measuring devices, utilizing elaborate instrumentation techniques, are very costly and can be justified only if the simpler and cheaper methods are unsuitable.

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[3] Foxboro Pty. Ltd., 23 Smith Street, Chatswood, N.S.W.

[4] Honeywell Pty. Ltd., 63–73 Ann Street, Surry Hills, N.S.W.

[5] Watson Victor Ltd., P.O. Box 144, Ryde, N.S.W. (Representing Hydrodynamics Inc., U.S.A.)

[6] John Morris Pty. Ltd., 61 Victoria Avenue, Chatswood, N.S.W. (Agents for Phys-Chem. Research Corp., U.S.A.)

[7] Tecnico Electronics Pty. Ltd., 53 Carrington Road, Marrickville, N.S.W. (Agents for Shaw Moisture Meters, England.)

[8] Esdaile & Sons Pty. Ltd., 31 Bay Street, Glebe, N.S.W. (Agents for Lambrecht, Germany.)

[9] Andrew Thom Ltd., 261 Broadway, N.S.W. (Agents for Casella, London.)

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[11] A.W.A. Ltd., Engineering Products Div., 47 York Street, Sydney, N.S.W. (Agents for Marconi Moisture Meters, England.)

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Rapid Test for Pinholes in Packaging Film

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The storage stability of processed foods packaged in flexible film containers may be seriously affected by the presence of minute pores or pinholes in the container material. Pores that completely penetrate the material increase the gas and vapour permeability of packages, cause a rapid loss of vacuum in vacuum-packed products, and may result in microbial contamination of sterile packs. Pores present in the individual layers of coated or laminated materials are less serious but, depending on the type of material, they may still have significant effects on the protective properties of the combination.

A QUANTITATIVE MEASURE of the overall permeability of a material can be made by the usual gas permeability methods, but these methods provide no information on the incidence and precise location of pinholes.

A useful account of the available methods for the detection of pores in packaging materials has been given by Becker (1963). Briefly, the methods involve the penetration through the pores and the subsequent detection of liquids, light, electrical or corona discharges, and gases.

This paper describes a sensitive method, referred to briefly by Becker (1963), based on the diffusion of ammonia through pores and subsequent detection on a paper coated with an ammonia-sensitive reagent. Some investigations of specific packaging material problems using the technique are discussed.

Apparatus and Procedure

The ammonia-sensitive reagent used in the present work was prepared by dissolving tartaric acid (100 g) in water (600 ml) and adding 60% ferric chloride (15 ml), 20% ammonia in water (120 ml), and 12% potassium ferricyanide (500 ml). This solution is stable for several weeks when stored in the dark. Sheets of white, semi-absorbent paper were coated on one side with the reagent and dried in the presence of light. The sheets at first are an olive-green colour, but upon exposure to light the ferric ions are reduced to ferrous ions which then react with ferricyanide to give the blue pigment ferrous ferricyanide (Turnbull's blue). This pigment is decomposed by excess ammonia to white ferrous hydroxide and ammonium ferricyanide.

Papers impregnated with Nessler's reagent and with a neutralized solution of silver nitrate and manganese nitrate were found to be less satisfactory than the ferricyanide reagent.

The apparatus (Fig. 1) consists of a circular Perspex cell divided into two compartments by the test specimen. The dimensions of the cell are not critical but for convenience the present cell was designed to accommodate the same 64-sq cm specimens used in the existing apparatus for determining the gas permeability of flexible film materials. The outlet from the top of the cell is connected by rubber tubing and glass T-pieces to a mercury manometer and a water pump. The vacuum applied to the top compartment is controlled by an adjustable hose clip downstream from the manometer. The bottom compartment is connected on one side to a Drechsel bottle partly filled with concentrated ammonium hydroxide and on the other side to the vacuum line downstream from the hose clip. Ammonia is swept into the cell by a current of air drawn through the ammonium hydroxide solution at approximately 150 ml/min. This flow rate may be achieved by adjustment of a second hose clip on the outlet line from the cell, or by inserting a capillary of suitable dimensions in the line.

The test specimen is placed on the flange of the cell and covered with the moistened reagent paper so that the reagent-coated side faces the specimen. With coated materials, the coating on the specimen must face the reagent paper. A neoprene gasket is positioned on the paper, and a metal screen having a diameter approximately 2 mm less than the internal diameter of the cell and gasket is fitted. The screen is used to prevent the moistened paper from sealing onto the flat

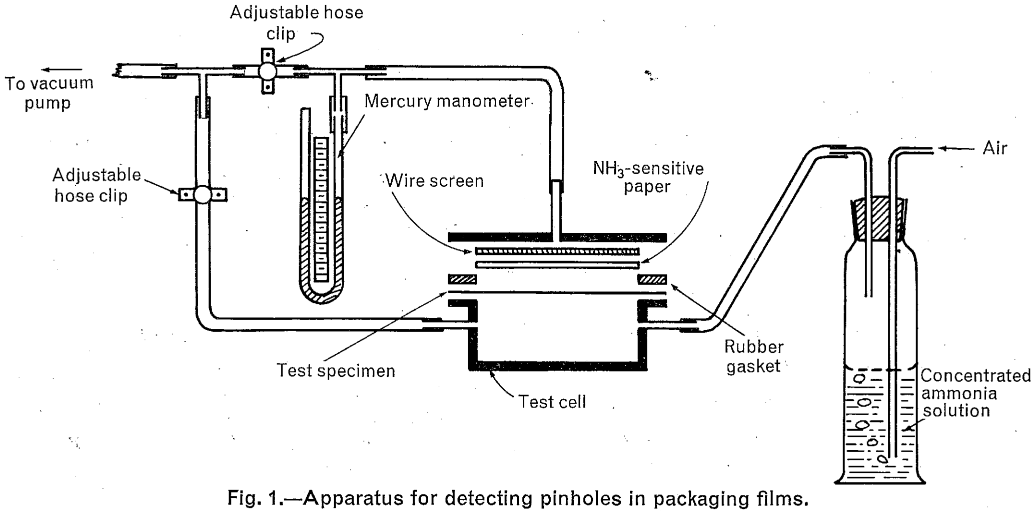

Fig. 1.—Apparatus for detecting pinholes in packaging films.

surface of the cell cover when a vacuum is applied. To prevent distortion of the specimen, the thicknesses of the screen and gasket should be similar. The cell cover is then fitted and clamped by four spring-back paper clips. With the water pump turned on, the hose clip is adjusted to give a vacuum of approximately 20 cmHg in the top of the cell. The tubing to the ammonia supply is then connected and ammonia drawn through the bottom of the cell. At the end of the test period, the ammonia line is disconnected and air drawn through the cell for approximately 30 sec to remove residual ammonia. The cell is then dismantled and the sensitized paper examined for white spots, which indicate discontinuities in the test specimen.

The time required for a test at a specific vacuum level depends on the nature of the film material; in the present series it was 15–240 sec using a vacuum of 20 cmHg. The optimum test time is one that gives small, sharply defined spots on the sensitized paper, and should be predetermined for each type of test material. Test times that are inconveniently short or long may be adjusted by decreasing or increasing, respectively, the vacuum on the top of the cell. However, when long test times are used, ammonia may permeate through an organic film free of pores by the solution-diffusion mechanism, resulting in a uniform discoloration of the reagent paper. Permeation of gases by this mechanism is independent of the total pressure and dependent only on the partial pressure difference of gas across the specimen, whereas diffusion through pores is dependent on total pressure. Hence the rate of diffusion of ammonia through pores can be controlled by the vacuum applied on the top of the cell.

Applications of the Method

The ammonia test is suitable for the detection of pores which completely penetrate packaging films, including aluminium foil, or those which are present in coatings on one side of a porous substrate such as paper. Papers coated on both sides may give positive results when pores are present in similar positions in each coating, but the spots observed would be an indication only of the porosity of the coating facing the sensitized paper. The method is not suitable for the detection of pinholes in coatings on non-porous film materials such as polymers, metal foils, regenerated cellulose, or glassine-type papers. Apart from these limitations, the observations reported below show that the test does have some important applications in both research and quality control on packaging materials.

PVDC-coated Papers

Because of their excellent barrier properties, vinylidene chloride–vinyl chloride copolymers (PVDC) are widely used as coatings on cellulosic and plastic substrates. The coatings on paper are applied in emulsion form in two or more separate layers, each of which is in turn dried. Pinholes in the coatings on non-porous substrates are relatively unimportant, but they may have a marked effect on the barrier properties of coated papers.

A series of opaque superglazed and glazed imitation parchment papers coated with two layers of PVDC and examined recently in this laboratory showed anomalous oxygen permeabilities (Table 1). The oxygen permeability determinations were made on 3–4 specimens of each batch of material by the volume-increase method described by Davis (1964).

The results of Table 1 show that 0·001 in. films prepared on glass plates from the same latex as used for the paper coatings gave low oxygen permeabilities which are comparable with those of another unsupported PVDC-type film evaluated in these laboratories (Davis 1968). In the absence of pinholes, the

Table 1
Oxygen Permeability of PVDC Film and PVDC-Coated Papers

Type of Paper	Coating Thickness (in$\times 10^{-3}$)	Oxygen Permeability (cc(s.t.p.)$\times$m$^{-2}\times$24 hr$^{-1}\times$76 cm^{-1}Hg at 20°C, 65% R.H.)	
		Range	Mean
Opaque superglazed	0·39	320–590	460
	0·58	310–480	390
	0·58	1·4–11	4·6
	0·70	140–470	310
Glazed imit. parchment	0·58	7·2–8·9	8·2
	0·58	96–130	110
	0·70	34–130	79
Unsupported film*	1·00	1·0–8·3	5·0

*Prepared by coating and drying the latex on glass plates.

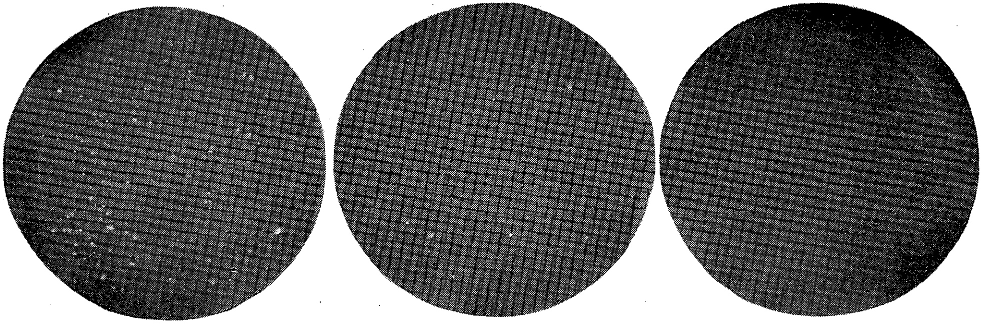

Fig. 2.—Pinholes detected in PVDC coatings on paper. Mean oxygen permeabilities of these samples were *left* 440, *centre* 80, and *right* 4·6 cc (s.t.p.) × m^{-2} × 24 hr^{-1} × 76 cm^{-1}Hg at 20°C, 65% R.H.

gas permeability of plastic films is inversely proportional to film thickness. The data in Table 1 show that there is no relation between coating thickness and oxygen permeability with either type of coated paper.

The presence in the coatings of pinholes, which may be caused by the method of application or the nature of the paper surface (Avery 1962; Poschmann 1965; Dierinckx 1967), was suspected as the cause of the variable results. Attempts were made to detect pinholes in the test specimens with ethyl alcohol coloured with methylene blue. Although isolated pinholes were found in some of the samples, the results were not consistent. The ammonia test was more sensitive and satisfactorily demonstrated that with both types of paper, specimens that gave oxygen permeability values higher than approximately 15 cc (s.t.p.) × m^{-2} × 24 hr^{-1} × 76 cm^{-1}Hg at 20°C contained one or more pinholes, whereas those that showed lower values had no pinholes. Some typical results of the pinhole test are illustrated in Figure 2.

In addition to the examination of specimens that give anomalous gas or vapour permeabilities, the ammonia test should also have applications as a rapid quality control test for the porosity of PVDC or other polymer coatings on paper. Experience with the method on PVDC-coated papers has shown that it is more sensitive to the detection of pores than methods based on penetration by liquids coloured by dyes.

Waxed Papers

Papers are frequently coated with wax or wax–polymer blends to reduce their water vapour transmission rates (W.V.T.R.). Pinholes in the wax coatings are known to have a pronounced effect on the W.V.T.R. of such materials, particularly when they are caused by the penetration of fibres that may function as wicks for the transfer of moisture. For maximum protection, therefore, wax coatings on papers should be sufficiently heavy to avoid pinholes. Furthermore, the coating should have maximum flexibility so that pinholing is kept to a minimum upon creasing the material.

Tests for pinholes and W.V.T.R. were made on samples of greaseproof paper (38 g/m^2) wet-waxed on one side with a wax-polymer blend at coating weights of 6·5 and 11 g/m^2. The paper with the heavier coating was also tested with a single crease across the centre of the specimen. The W.V.T.R. tests were made at 25°C, 75% relative humidity (R.H.) by the British Standards Institution (1959) method with the wax coatings facing the high R.H.

The mean W.V.T.R. results (Table 2) show that the uncreased material coated at 11 g/m^2 was less permeable to water vapour than that

Table 2
Mean W.V.T.R. of Greaseproof Paper Coated with a Wax–Polymer Blend

Coating Weight (g/m^2)	W.V.T.R. (g × m^{-2} × day^{-1} at 25°C, 75% R.H.)
6·5	4·3*
11	1·0*
11	6·0†

* Flat. † Creased.

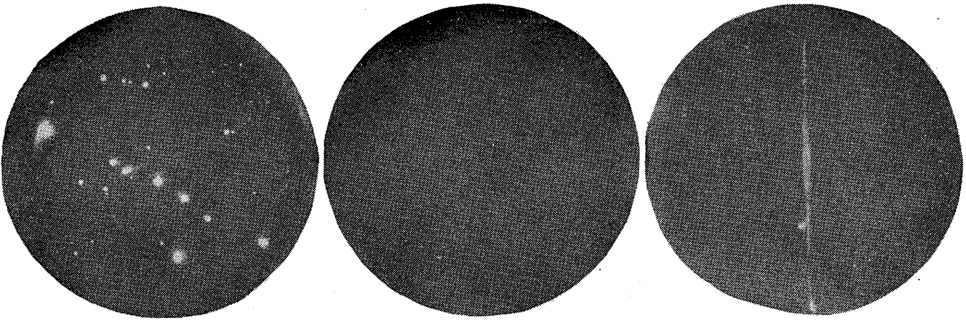

Fig. 3.—Pinholes detected in creased and uncreased waxed papers. Wax coating weights (g/m^2) were *left* 6·5 (uncreased), *centre* 11 (uncreased), *right* 11 (creased).

coated at 6·5 g/m^2. A single crease across the specimens, however, was sufficient to raise the mean W.V.T.R. of the 11 g/m^2 coating to a value slightly higher than that of the lighter coating. The results of the pinhole tests, illustrated in Figure 3, are consistent with the W.V.T.R. results. The paper coated with wax at 6·5 g/m^2 showed evidence of more pinholes than the more heavily coated paper, but a crease across the latter material increased its porosity.

These observations suggest that the ammonia test should be useful for the rapid determination of both porosity and resistance to creasing of wax and wax–polymer coatings on papers.

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CSIRO Meat Research Laboratory

The second stage of the Meat Research Laboratory was completed in April 1969.

Architecturally, the two stages of the laboratory were designed as one building complex for meat research, but were so planned that the first stage could operate as a self-contained entity. The stage II laboratory block is linked by the administration building to the stage I laboratory block, giving a total of 23 laboratories.

The second stage, with a floor area of 25,500 sq ft, was built at a cost of $630,000. The additions include 10 laboratories and associated special-purpose rooms, and 4 cold laboratories. Extension of the administration wing includes a conference room, canteen, and additions to the library. The services building was extended by the provision of a new workshop, store, meat processing area (2470 sq ft), meat cutting and preparation area (420 sq ft), and additional freezing and chilling facilities. The four new freezing rooms are designed for operation at −40°C and two of these are completely jacketed, so preventing heat leakage through the insulation to the products being stored. Holding yards, pens, and surgery for live animal experiments are located separately.

The whole laboratory has a floor area of 47,600 sq ft, and is erected on 15 acres of land at Cannon Hill, Qld. The total cost of $1,210,000 for the project was shared by the Australian Meat Research Committee, the Australian Meat Board, and the Treasury.

At the time of completion of stage II, the laboratory had a staff of 64, including 25 scientists. Working funds are derived from a levy on sheep, lamb, and cattle slaughtered, with a matching grant from the Commonwealth Government, as provided under the Livestock Levy Act.

The laboratory is the principal centre for research and scientific information for Australia's expanding meat industry. It now has facilities for a total staff of 100, including 40 scientists with special knowledge of such subjects as engineering, physics, microbiology, physiology, biochemistry, electron microscopy, and histology. A comprehensive research programme on beef, mutton, and lamb is carried out into such interrelated fields as muscle science, meat science, and meat technology. A separate and important function of the laboratory is extension and liaison with industry.

The research programme of the laboratory concerns the technical problems associated with improving the efficiency of conversion of the animal from the time it is yarded at the farm until it reaches the consumer as meat.

Emphasis is being given to research into ways of improving the quality of meat for the export and local market. Much of the variation in meat quality is due to such factors as age, sex, and nutrition and some of these are under the control of the farmer. But the quality of meat is also affected by the way in which the animals are treated between the farm and the slaughter floor and by the handling of the meat between the slaughter floor and the consumer.

The completion of this second stage will result in greatly improved facilities for staff and equipment, and the provision of facilities on site for work with experimental animals will be invaluable to the research programme.

NEWS FROM THE DIVISION OF FOOD PRESERVATION

Appointments

Miss Elizabeth Wardle has been appointed to the Microbiology Section of the Division to assist with experimental studies on the properties and structure of bacterial spores and with investigations on the microbial spoilage of foods. Miss Wardle graduated in science at the University of Adelaide in 1963. She was a demonstrator in the Biochemistry Department at the University of Adelaide for several years.

Overseas Travel

Mr. S. M. Sykes, leader of the food technology group at the CSIRO Regional Laboratory, Hobart, Tas., left for a three-month period overseas on April 7. Mr. Sykes is visiting the United States, Great Britain, and Europe for the purpose of studying current research work and the state of industry in the following fields: processing and quality measurement of potatoes, processing of apples, canning and freezing of small fruits, and canning and freezing of vegetables.

United Nations Fellow

Miss Leda Pupo, a food technologist from the Tropical Centre for Food Research and Technology, Campinas, São Paulo, Brazil, is spending a year in the Division gaining experience in the sensory evaluation of foods and beverages. Miss Pupo is attached to the Division's Taste Test Unit at North Ryde, where she took up duty on April 8.