Blown cellulose fiber thermal insulations. Part 1: density of cellulose fiber thermal insulation in horizontal applications

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PREFACE

The heat loss from existing buildings represents a major part of the nation's energy consumption and most levels of government are advocating the addition of insulation to these structures. Few insulating materials are suitable for an extensive reinsulation program and there are insufficient quantities of those that are suitable. Cellulose fibre materials have been used for reinsulation but very little has been published about this type of insulation and its performance has not been well documented.

The committee of the Canadian Government Specifications Board charged with the responsibility of preparing a Canadian standard on cellulose fibre insulation asked the Division of Building Research to develop a method to determine the density of the material at two stages: as blown and after a typical amount of settlement. This report is the response to their request. The results have a wider application and they will be submitted for presentation at the ASTM C-16 Symposium on Thermal Insulation to be held in Philadelphia in September 1977.

Ottawa
June 1977

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Director
DBR/NRC

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

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BLOWN CELLULOSE FIBER THERMAL INSULATIONS

PART 1: Density of Cellulose Fiber Thermal Insulation in Horizontal Applications

by M. Bomberg and C. Shirtliffe

Checked by: D.G.S. **Approved by:** L.W.G. **Date:** June 1977

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1. Introduction

Cellulose fiber insulation consists of small tufts of fiber and minute pieces of paper mixed with fine particles of chemical additives. The thermal performance of the cellulose fiber insulation depends not only on the composition and structure of the material as produced during the milling operation but also on the way the material is fluffed and configured while being blown into place. The blowing process produces a structural network of fibers. Both the density and the stability of the structure depend on the conditions of blowing.

All blown fibrous insulations can be assumed to settle after being applied. The density may gradually increase until some equilibrium is reached. The density changes may be too small to be measured over the span of a few months. Regardless of what actually occurs, the density at this stage is often called settled density.

The settled density can only be determined by making measurements in the field. Results of field measurements, however, have shown a considerable scatter. To explain this scatter it is necessary to study the factors that have a significant effect on the density during blowing and on the subsequent settlement. Both sets of factors and the scope of the study on relative significance of the factors are shown in Tables 1 and 2.

The objective of this study was to find a method to produce samples for testing that are representative of the material as it exists in attics of buildings. Such a method must consist of two parts:

1. the technique for blowing samples;
2. the method of obtaining settled density.

2. Scope of the Research

The goals of this study were to:

(i) determine the effect of transport and placement conditions on the initial density of insulations;

(ii) establish a standardized method for producing specimens of blown cellulose fiber insulations;

(iii) investigate the factors that cause the material to settle after placement;

(iv) establish a standardized method of producing settlement in the specimens that yields settlements comparable with those found in field studies.

2.1 Machines used in the tests

A number of different designs of blowing machines are available. Most of them break the compressed material from the bags into small lumps which pass through the blower thus producing fine particles carried by the air stream.

Three blowing machines were used during the study.

Machine 1 was a Shelter Shield blowing machine produced by Diversified Insulations Inc., Minneapolis, Minnesota. It was equipped with two 10-fingered agitators in the hopper. The air setting was continuously variable and the indicator was marked at 1/8-in. intervals from 0 to 2 in. A 1-hp Tornado blower (model 8805) was used on the machine.

Machine 2 was an Incel Corporation blowing machine with one agitator in a hopper. It was produced by the Incel Corp., Bluffton, Indiana. The agitator had relatively long "fingers" which forced an ample supply of insulation into the blower. This machine used a 1.5 hp blower Model RMI 8950, produced by Robbins and Myers, Springfield, Ohio. The air setting was continuous but was not graduated.

Machine 3 was a Thermtron blowing machine produced by Thermtron Inc., Fort Wayne, Indiana. Its three agitators, each having a different rate of rotation, provided a more than adequate supply of material to the blower. The unit had twin blowers, one 0.8 and one 1 hp. In almost all applications the 0.8 hp blower (model HP33WS) produced by Clement's Manufacturing Company, Chicago was used. Unlike machines 1 and 2 the air setting was in discrete steps. There were five holes with diameters of about 1/8, 1/4, 1/2, 1 and 1 1/4 in. Adjustment of air setting is shown in Fig. 1. The same value of air setting, i.e., 3/8 in., does not represent the same rate of air flow in each of the three machines tested.

All three machines were supplied with standard 2-in. inside diameter corrugated plastic hose. In the preliminary series, 50- and 75-ft lengths were used; in the main testing series a 100-ft (30.5-m) length was used. The hose was used without a nozzle for blowing onto horizontal space. (For simplicity, the end of the hose is termed the nozzle in this report.)

2.2 Materials used in the tests

All the 35 materials used for the tests were obtained from the regular production of manufacturers in the USA and in Canada. The fire retardant used was either aluminum sulphate or a combination of two or three of the following chemicals: aluminum sulphate, borax, boric acid, ammonium sulphate and calcium sulphate. The formula and quantity of fire retardant is not known exactly but in general the amount varied from 16 to over 30 percent by weight. The source of the cellulose was newsprint except in one case. The moisture content of the paper varied due to the wetness of the cellulose stock and the variable hygroscopic properties of the fire retardants. The moisture content of the products varied between 5 and 10 percent by weight.

The materials were numbered randomly from 1 to 35.

3. Effect of Transport and Placement Conditions on the Applied Density

3.1 Effect of nozzle height and hose length

Changes in density caused by hose length and the height of the end of the hose above the machine were checked by blowing the same material in two different ways. In the first, the hose end was 11 ft above the machine. In the second, the end of the hose was only 3 ft above the base of the machine. In each case a 3/8-in. air opening was used; the end of the hose was directed horizontally. Three containers 36 by 14 by 6 in. were filled. The densities obtained in these two tests were 1.97 and 1.98 lb/ft^3. It was judged that the height of the nozzle above the machine did not have a significant effect on the density of the material transported to the nozzle.

The effect of the hose length was checked by blowing the same material twice, that is, recycling it. Several materials were recycled and the final density compared with the density after the first blowing. The densities of the specimens produced from the recycled materials were almost identical to the original densities. The variations were less than 1.5 percent or 0.03 lb/ft^3. In each case this is well within the standard deviation of 0.04 to 0.11 lb/ft^3.

3.2 Effect of specimen size and shape of the container

The effect of shape and size of the container was studied to establish a controlled method for producing specimens of blown cellulose fiber insulations. Four different-size containers were used in a series of tests. Two, three, four or six containers of each size were filled with each material tested. The material blown into the small (17- by 17- by 3-in. or 17- by 17- by 6-in.) containers showed greater variations in density than that blown into the larger (36- by 14- by 4-in. or 36- by 14- by 6-in.) containers. The variations were probably caused by the impact of the material on the walls of the container.

The importance of size and depth of the container is shown in Fig. 2. Two different techniques of placing the insulation were used: horizontal blowing from a height of 36 in. and 10 degrees upwards blowing from a height of 11 in.

The effect of container size and depth depends on the blowing technique. When the material was blown with the nozzle 11 in. above the specimen and pointed 10 degrees upwards, the effect of depth became negligible. The effect of container size was less than 5 percent.

Containers 36- by 14- by 6-in. were selected for density measurements and containers 11- by 11-in., 6- and 12-in. deep were selected for the climatic cycling.

2.3 Effect of air setting

Products 10, 19 and 23 were blown using Machine 2 with the nozzle pointed horizontally at a 3-ft height and various air settings. The results are plotted on Fig. 3.

Changes in the air setting significantly affect the density of the cellulose fiber insulations. With Machine 2, the minimum density was obtained at the 1½- and 2-in. air settings. The density of product 23 varied about 20 percent with air setting. The density of Product 10 varied about 15 percent, but that of Product 19 varied only about 10 percent.

2.4 Combined effect of hose position and air setting

Figure 4 illustrates the different positions of the nozzle used in a series of tests. In each case the air settings were varied. The results of the tests are listed in Appendix A to this paper.

The variation in density caused by changes in the air settings when blowing downwards from a 6-in. height is shown in Fig. 5. Products 3 and 12 when blown with Machine 1 gave a minimum density at the air setting between 1/4 to 1/8 in. The minimum density was obtained with the same machine at air setting between 1½ to 2 in. when the material was blown from 3 ft. The air setting cannot be considered as an independent variable. The mass of material per volume of air or the rate of mass flow of the material and the air velocity at the nozzle might be better measures than the air setting, but these were not measured in the tests.

The effect of the air setting on the density can vary with the design of the machine. This is shown in Fig. 5 where it can be seen that Product 12 when blown with Machines 1 and 2 gave densities differing by several percent. There was a higher air velocity at the nozzle for the same air setting with Machine 2 than with Machine 1. Variations from bag to bag of the products were eliminated from most of the tested materials by recycling them 2 to 4 times. This produced a material that was more uniformly fluffed and allowed a better comparison of the machines.

The three techniques for blowing cellulose fiber, each using a suitable air setting, were compared to see if the same density could be obtained on different machines. Figure 6 shows the density of three products as determined on three blowing machines and different blowing techniques. Differences of up to 20 percent for the same material using different blowing machines occurred. These differences can be significantly reduced if the optimum air setting is selected for the given machine. By a series of preliminary blowings, one can find the air setting that will give the minimum density and use it for the actual test. There are limitations to this approach since the flow becomes nonuniform if the air setting is too low and excessive dusting occurs if the air setting is too high. The air velocity at the nozzles could not be standardized because of the limited range of adjustment on the machines. The sensitivity of the density to this velocity made it impossible to standardize the blowing technique with the nozzle pointed downward. Figure 6 shows that the density was not seriously affected by this veolicty when the hose was pointed 10 degrees upward.

4. Recommended Method for Producing Specimens of Blown Cellulose Fiber Insulations

The hose should be pointed 10 degrees upwards and the end of the hose kept 11 in. above the surface when blowing. This method is sufficiently reproducible to be accepted as the standard blowing technique. The air setting can be selected by conducting a series of tests with the given machine. A minimum of four air settings should be used. Widely different air settings should be used first. The lowest setting should be that which will give a uniform flow of material and the highest that which will not produce excessive dust. Two intermediate air settings should then be used. The air setting which produces the minimum or near minimum density should then be chosen for the actual test. A minimum of four containers 36- by 14- by 6-in. should be used for the actual test.

Two products were blown with three machines (the results are shown in Fig. 7). For Product 25 the greatest variation in density using the three machines was 4 per cent, for Product 2 it was only 2.4 percent. This is much less than the 20 percent difference found for the same product using any of the other blowing techniques. The standard deviation was less than 0.04 lb/ft^3. This method appears to be simple and effective even though it is not the usual method of installing insulation in attics by blowing.

5. Reproducibility of Density Determinations

Table 3 gives the results of tests by blowing horizontal at a 3-ft level. All products were manufactured from newsprint except Product 23 which was manufactured from cardboard. The standard deviation of the tests on Product 23 was about twice that determined when testing newsprint-based cellulose fiber insulations. Only 4 percent of the tests had a standard deviation in excess of 0.11 lb/ft^3; the average standard deviation was 0.067 lb/ft^3. Selecting six samples, a confidence level of 95 percent and assuming a t-distribution function, the density should fall within the confidence interval: $2 \times t \times s/\sqrt{n} = 2 \times 2.571 \times 0.067/\sqrt{6} = 0.14$ lb/ft^3. The densities of the tested materials were between 1.4 and 2.6 lb/ft^3 with an average value of about 2.1 lb/ft^3. These figures show that the density determined using six samples should, with a 95% confidence level, fall within 10 percent of a true average for 1.4 lb/ft^3 specimens and 5 percent of the true average for 2.6 lb/ft^3 specimens.

An estimate of the accuracy of the proposed blowing technique can be made using the mean standard deviation determined from tests performed according to the proposed method. The mean standard deviation for four density measurements in containers 36- by 14- by 6-in. was 0.047 lb/ft^3. Using $t = 3.182$ for four samples, the 95 percent confidence interval becomes 0.15 lb/ft^3. That is, the density determination with four samples tested according to the new method will be practically as accurate as the determination with six samples and horizontal blowing from a height of 36 in. These figures reflect, primarily, only the variability of the product from bag to bag since 2 to 3 bags of material are used for density determinations. They do not show the differences that occur between batches from different production lots. Several production lots would have to be tested to examine the product variability, but this is beyond the scope of this research.

6. Field Measurements on Cellulose Fiber Insulations

During March 1977 the density of Products 3, 10 and 12 were measured in situ after being exposed in Ottawa for 2 winters. The materials in two 2-storey and three 1-storey houses were tested. Insulation had been added to existing glass fiber batts or loose-fill material fibers in the fall of 1975. The thickness of the layer of cellulose fiber insulation varied between 4 and 10 in.

The density of the material was determined in situ in the following way:

(i) after removing an adjacent section of cellulose, a metal sheet was slowly inserted horizontally under the cellulose insulation;

(ii) a 10- by 10-in. area of material on the metal sheet was selected and 5 thickness measurements were made;

(iii) a 10- by 10-in. box with sides 10 in. high and open top and bottom was pushed through the insulation to the metal sheet;

(iv) the insulation within the metal box was removed and weighed. It was then dried in a 50°C oven and reweighed.

The results of these tests are shown in Table 4.

Product 10 from House 1 was packed into plastic bags and taken to the laboratory. After selecting a proper air setting, five 36- by 14- by 10-in. containers were filled, and the density measured. The mean density was 1.93 lb/ft^3 and 1.94 lb/ft^3 for the standard and the deep containers respectively. The density as blown in the laboratory of 1.94 lb/ft^3 and the density determined in situ of 2.93 lb/ft^3 can be compared directly since it has been demonstrated that recycling has little effect on the density.

The 51 percent apparent increase in density may not all be due to the settlement since the density at which the material was actually applied cannot be determined. The variation in density found in the laboratory tests on the material removed from the attic was 3 percent. The decrease in density was not due to a higher moisture content since the material that was reblown in the laboratory contained the actual moisture. The hose position would not cause a variation greater than 8 percent. It seems reasonable to assume that there was a settlement in the material of about 40 percent. In other houses the settlement seemed to be much lower. In House 2 Product 10 had an apparent increase in density of 36 percent indicating probable settlement of about 25 to 30 percent. In Houses 4 and 5 where Product 12 was used, probable settlements are in the range of 15 to 30 percent. In House 3 where Product 3 was used there was no significant settlement. The only density change was that caused by the pick-up of moisture. The variability in these estimations of settlement suggests a need for a study of the factors influencing the settlement of cellulose fiber insulations.

7. Laboratory Measurements of Moisture Content in Horizontal Layers

The ability of the material to absorb moisture was studied under laboratory conditions. The material was placed in containers located between two steady environments, one at 73°F and 50 percent and the other at a temperature below the dew point so that internal condensation would occur close to the bottom of the container. The bottom surface of the containers was drilled with a few hundred small holes allowing excessive moisture to pass to an underlying porous fiber board layer.

Three series of tests were conducted with different temperature gradients. The gradients were chosen so the zone of condensation varied in thickness. The resulting moisture contents in the condensation zones are shown in Table 5.

Moisture content in the condensation zone appears to be in the range 150 to 200 percent by weight except for Product 23, which was made of cardboard. This specimen absorbed less moisture.

Moisture accumulated only in a very narrow layer adjacent to the lower surface of the material; the bulk of the material remained relatively dry. Moisture contents between 8 and 11 percent at the upper surface (Table 5), lie in the same range as average values determined in situ.

8. Effect of Impact and Oscillation of the Climatic Conditions on the Settlement of the Material

From 1974 to March 1977 the thermal resistance of cellulose fiber insulations tested at the Division of Building Research were determined using an 18-in. vertical guarded hot plate apparatus. Two matched specimens, 18 in. square and either 3 or 6 in. thick, were placed in polyethylene-covered frames and held in a vertical position on either side of the heater plate. Settlements occurred during the testing period which usually lasted 2 to 5 days. The amount of settlement in this period is shown in Table 6. Settlement occurred in every case even though it was different for the two thicknesses. The extent of the settlement was dependent on the amount of support from the surrounding surfaces. It was approximately 4 percent for 3-in. specimens and 10 percent for the 6-in. specimens.

8.2 Settlement during air pressure changes

A cylindrical container with a diameter of 5¾ in. and height 12 in. was filled to the depth of 7.42 in. with a part of product 10 that was taken from House 1. The density of the material in the container was 2.40 lb/ft^3.

A top was placed on the container and the pressure of the air in the cylinder was raised to about 15 mm Hg above atmospheric pressure. It was slowly lowered to about 15 mm Hg below atmospheric pressure. The pressure cycle lasted about 15 min. The cycling was continued for 48 h, then the container was opened.

The final thickness was 7.42 in. No measurable settlement had occurred. The cycling of the air pressure is not a significant factor.

8.3 Settlement due to humidity changes

Product 10 was blown into two open containers 17- by 17- by 7-in. at densities 2.13 and 2.14 lb/ft^3. The containers were exposed alternately to 70°F and 50 percent RH then 70°F and 98 percent RH in 3- or 4-day intervals for a total of two weeks. Two cycles were completed. The final densities were 2.47 and 2.51 lb/ft^3. These were 16 to 17 percent higher than at the beginning. The settlements were also 12 to 13 percent greater than the settlement of the samples held at constant humidity.

Product 3 was tested in the same way. The total settlement was 9.5 percent.

Product 2 was also blown into two frames 11 by 11 by 6 in. and two frames 11 by 11 by 12 in. The frames were placed in a 40°F and 98 percent RH climatic chamber. After two days the thickness was measured. The settlements were found to be 5.2 and 6.2 percent for the 6-in. thick specimens and 7.4 and 8.6 percent for those 12 in. thick.

Humidity changes play a prominent role in the settlement of the material. The thickness of the specimen appears to influence this effect. Tests should be performed on two sets of the specimens with different thicknesses.

8.4 Settlement due to temperature changes

Specimens of Products 3 and 10 were placed in a set of open containers, 4.8 and 12 in. deep. The containers were placed in a climatic chamber where the temperature was cycled, within a 24-h period, between 40 and 70°F. The relative humidity of the air was maintained at approximately 98 percent.

The thickness of the material was measured after 5 and 8 days of exposure (Table 7). The settlement for the 4-in. thick specimens was not significant; for the 12-in. thickness it was 6 to 8 percent. These results indicate that temperature variations alone may be of secondary importance in settlement but together with changes in relative humidity and the elapse of time they may contribute to significant settlement. The settlement appears to depend also on thickness of the tested specimen.

8.5 Settlement due to impact

Two containers, 36 by 14 by 6 in. deep and each weighing about 9 lb, were filled with Product 1 and then dropped 3 times from a height of 6 in. onto a concrete floor. The density was measured before and after dropping. This process was continued for a total of 42 drops; the density versus the number of drops was plotted (Fig. 8). The scatter in the results becomes larger with increasing number of drops. The effect of each additional drop decreases continually as would be expected.

The densities of a number of specimens of different products were measured after three, six and twelve drops from a 6-in. height. The results are listed in Table A-9. Figure 9 shows on a semilogarithmic plot the dependence of the average of specimen densities on the number of drops.

Figure 10 shows the effect of the initial density on the dependence of density on number of impacts. The increase in density in the drop test does not appear to depend on the initial density. A product of light density does not settle more than denser, more compacted, materials. Further testing has shown that the increase of density with impact (Fig. 9) appears to be representative of all the cellulose fiber insulations blown with this type of equipment.

Material taken from House 1 and reblown in the laboratory had a mean density before settlement of 1.93 lb/ft^3. When dropped 18 times from a 6-in. height, the density reached 2.31 lb/ft^3. This density was still far less than the in place density of 2.93 lb/ft^3. It appears that it is not possible with the drop test to produce as much settlement as is found in situ.

9. Recommended Method for Producing Settlement in the Specimens

Both temperature and humidity vary considerably in attics. These fluctuations can be assumed to play an important role in the settlement of the insulation material.

The following procedure is recommended for producing a settled density:

(i) blow the material into 36- by 14- by 6-in. containers and determine density as blown. (The procedure is described in this paper in Section 4):

(ii) blow two containers 11- by 11- by 6-in. and two containers 11- by 11- by 12-in. using the same blowing techniques;

(iii) drop four 36- by 14- by 6-in. containers 6 times from a 6-in. height onto a concrete floor;

(iv) measure the thickness and calculate the percent decrease in thickness during the drop test (designated as S_d);

(v) place all the filled containers in a climatic chamber at 40°C and 98 ±1 percent RH for four days;

(vi) remove the containers from the chamber and place in a conditioned room with climate 73°F and 50 ±5 percent RH for at least three days;

(vii) repeat steps (v) and (vi) until four exposures in the 40°F chamber have been completed;

(viii) measure the thickness and calculate the percent decrease (designated S_c);

(ix) the settled density is determined by multiplying the density as blown into the 36- by 14- by 6-in. containers by the factor $s = (100 + S_d + S_c)/100$. If settled densities for 6- and 12-in. thick specimens differ by more than 5 percent both values should be noted. If the difference is 5 percent or less, only one value of settled density need be reported.

Table 8 shows density as blown, percent decreases during the drop test and climatic cycling and settled density for four tested materials.

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TABLE 1. VARIABLES AFFECTING DENSITY OF BLOWN CELLULOSE FIBER INSULATIONS

FACTORS			SCOPE OF STUDY IN THE RESEARCH
ELEMENT	VARIABLE	EFFECT	
The material	degree of milling chemical content moisture content	- density variations: batch to batch, and bag to bag	bag to bag variability
The machine	design blower design air setting	- feeding to the blower - flow path changes - material to air ratio	3 machines with 3 blower designs studied
The hose	size, design and length	- fluffing during transport	one size and design used air pressure in the hose studied - recycling of material performed
The nozzle	geometry	- changes in air pressure and the flow of material	no nozzle used for horizontal applications
Position of the nozzle	relative to the machine relative to the specimen	- density changes due to vertical transport - impact on the material already blown	0 and 3 ft. height examined 3-12 in. and 36 in. examined
The size of the container	shape and area depth	- flow pattern - impact of material on walls and material already in the container	2 shapes and 4 sizes examined 3 depths examined

TABLE 2. VARIABLES AFFECTING SETTLEMENT OF BLOWN CELLULOSE FIBER INSULATIONS

FACTOR	CAUSE	EFFECT	STUDY	CONCLUSION OF THE STUDY
static electricity	friction	repulsive forces between particles	general observation	not significant
variations in air pressure	barometric pressure temperature	non-reversible deformation	air pressure variation	not significant
variation in temperature	climate	reversible thermal movements non-reversible deformation	thermal cycling	little significance
humidity variation	climate moisture accumulation in attics	adsorption, absorption and desorption, interparticle capillary forces causing movements	humidity cycling	significant
gravity	gravity field	time dependent displacement	observation in laboratory	little significance
vibration impact	environment	particle displacement	impact (drop test)	significant

TABLE 3. Density of horizontal layer in lb/ft^3 determined for several products by horizontal blowing on 3-ft level into containers mainly 36x14x4 or sometimes 36x14x6. Tests carried out in 1975 and 1976 at DBR/NRCC

Product	Machine	Density in containers, lb/ft^3							
		1	2	3	4	5	6	Mean	Standard Deviation
1	2	2.43	2.43	2.33	2.25	2.23	2.29	2.33	0.08
1	2	2.27	2.29	2.34	2.22	2.13	2.07	2.22	0.10
2	2	1.82	1.83	1.83	1.87	1.79	1.80	1.81	0.02
2	3	1.76	1.58	1.78	1.83	1.82	1.80	1.76	0.09
3	2	2.32	2.43	2.29	2.21	2.41	2.40	2.34	0.09
4	2	1.76	1.76	1.74	1.69	1.71	1.72	1.73	0.03
5	2	2.23	2.32	2.34	2.08	2.11	2.15	2.21	0.11
6	2	2.08	2.13	2.08	2.09	2.12	2.11	2.10	0.02
6	2	2.09	2.12	2.10	2.14	2.11	2.16	2.12	0.03
7	2	2.10	2.07	2.03	1.98	2.08	2.20	2.08	0.07
8	2	1.95	2.14	2.15	2.08	2.28	2.29	2.15	0.13
9	2	1.39	1.41	1.37	1.37	1.35	1.41	1.38	0.02
10	2	1.96	2.03	2.12	2.10	2.11	2.21	2.09	0.09
11	4	1.94	2.01	2.06	2.01	1.97	1.96	1.99	0.04
12	2	2.48	2.54	2.41	2.59	2.37	2.29	2.45	0.11
17	2	1.92	2.11	2.21	2.20	1.99	2.19	2.10	0.12
19	1	2.11	2.10	2.06	2.06	-	-	2.08	0.03
20	1	2.43	2.49	2.53	2.50	2.39	2.31	2.44	0.08
21	1	2.14	2.18	2.17	2.15	2.16	2.11	2.15	0.02
22	1	1.86	1.91	1.98	1.92	1.93	2.02	1.94	0.06
23	1	2.19	2.63	2.71	2.71	2.57	2.40	2.54	0.20
24	1	1.89	1.90	1.94	1.92	2.03	2.02	1.95	0.06

TABLE 4. Density determined in attics in five houses in Ottawa during March 1977

Property Tested	House 1 product 10	House 2 product 10	House 3 product 3	House 4 product 12	House 5 product 12
mean layer thickness, in.	9.0	4.2	4.0	4.0	4.9
mean moisture content, % weight	7.0	9.9	10.2	9.8	9.3
density, lb/ft^3 of wet material	3.09	2.83	2.19	2.63	2.53
	2.99	2.51	2.20	2.40	2.83
	2.86	2.73	2.26	2.56	2.84
	2.86	2.62	2.17	2.55	2.67
	3.03	2.64	2.41		2.68
	2.87	2.72	2.55		3.22
	2.80	2.62	2.14		
	2.97	2.44			
mean wet density, lb/ft^3	2.93	2.64	2.27	2.53	2.80
mean density of a dry material, lb/ft^3	2.82	2.40	2.06	2.31	2.65
layer below the blown material	glass fiber batt	glass fiber batt	blown glass fiber	glass fiber batt	blown rockwool

TABLE 5. **Moisture contents at upper and lower surfaces of the cellulose insulation exposed to the vapour condensation test**

Prod. No.	Series 1		Prod. No.	Series 2		Series 3
	Upper	Lower		Upper	Lower	Lower
10	9.0	44.0	1	9.5	181	224
12	10.1	47.7	2	10.6	208	-
19	9.4	52.1	3	11.0	185	214
21	8.2	53.4	22	10.6	151	209
25	8.3	48.7	23	6.4	56	149

TABLE 6

Density changes during thermal resistance testing in 18 inches GHP apparatus at DBR:NRCC

Test Number	Product Number	Density as blown lb/ft^3	Using 3-in. frames for R-value test			Using 6 in. frames for R-value test		
			before	after	%change	before	after	%change
1	3	2.35	2.48	2.62	5.6	2.66	3.04	14.3
2	4	1.66	1.71	1.78	4.1	1.84	2.04	10.9
3	5	2.20	2.40	2.48	3.3	2.29	2.64	15.3
4	6	2.12	2.16	2.26	4.6	2.25	2.60	15.6
5	7	2.08	2.21	2.26	6.8	2.46	2.64	7.3
6	8	2.15	2.11	2.25	6.6	2.19	2.54	16.0
7	9	1.38	1.46	1.49	2.1	1.50	1.54	2.7
8	10	2.09	2.18	2.22	1.8	2.15	2.37	10.2

mean 4.4% mean 9.8%

Table 7

Effect of temperature cycling between 40°F and 70°F with constant relative humidity at 98% RH on settlement of cellulose fiber blown insulation

Container depth, in.	Product	% change after	
		5 days	8 days
4	3 10	0 0	0 0
8	3 10	0 1	1 4
12	3 10	5 6	6 8

TABLE 8. Density changes during settlement testing

Product Number	Density as blown lb/ft^3	Settlement in Percent								Settled Density lb/ft^3
		Dropping				Cycling of Samples				
						6 in.		12 in.		
26	2.58	9.4	9.7	9.3	11.5	7.9	9.0	8.3	9.5	3.06
25	2.33	10.4	9.3	13.3	11.5	11.4	11.1	11.9	10.4	2.61
27	2.86	10.7	12.0	11.8	10.3	10.0	10.8	10.5	11.0	3.48
10*	1.93	14.6	9.8	12.7	-	20.9	20.1	21.8	20.0	2.57
28	2.16	9.4	9.7	8.4	9.7	13.5	12.5	12.8	13.1	2.64
29	1.91	10.5	7.7	10.0	9.7	10.4	10.6	13.0	13.4	2.32
30	2.23	11.6	7.0	9.3	9.1	10.0	6.0	9.2	8.6	2.63
31	2.34	11.7	10.7	9.9	8.6	6.9	8.0	9.2	7.9	2.77
32	2.38	9.0	9.2	8.7	9.9	6.8	7.1	9.7	9.9	2.80
6	2.07	8.6	9.0	9.3	9.4	7.9	8.8	8.5	9.6	2.44
33	2.94	13.5	11.1	11.4	9.6	13.0	10.9	11.3	10.7	3.61
5	2.14	9.8	10.5	12.1	9.3	11.0	9.3	11.7	10.8	2.59
34	1.92	9.6	9.8	10.9	10.3	14.3	15.5	14.0	15.0	2.40
35	1.88	10.3	9.2	9.7	10.0	10.3	10.6	13.8	12.8	2.29

* Material removed from the house

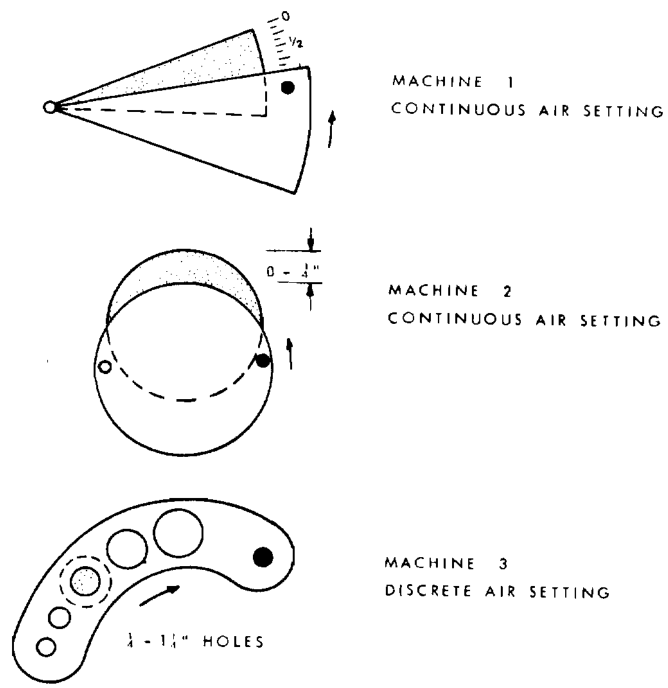

FIGURE 1

ADJUSTMENT OF AIR SETTING IN THE THREE TESTED MACHINES

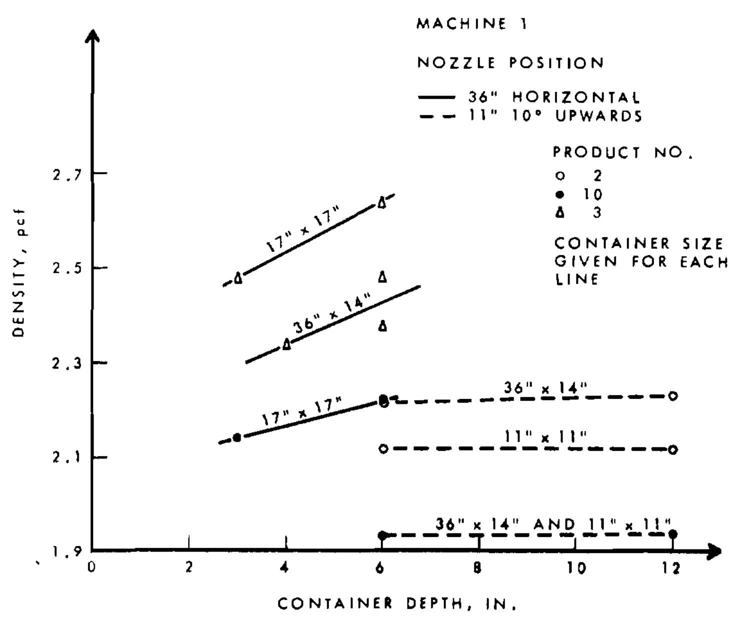

FIGURE 2

DENSITY AS AFFECTED BY THE THICKNESS OF THE BLOWN LAYER AND CONTAINER DIMENSIONS

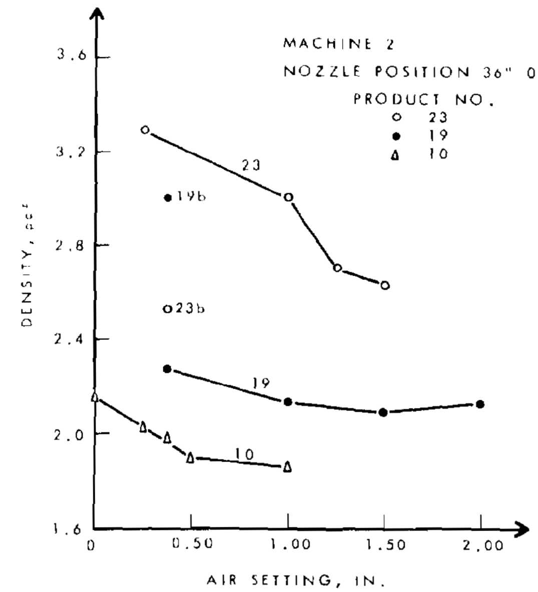

FIGURE 3

EFFECT OF AIR SETTING ON THE DENSITY OF SPECIMENS PRODUCED WITH MACHINE 2 BLOWING HORIZONTALLY FROM 36 INCH HEIGHT

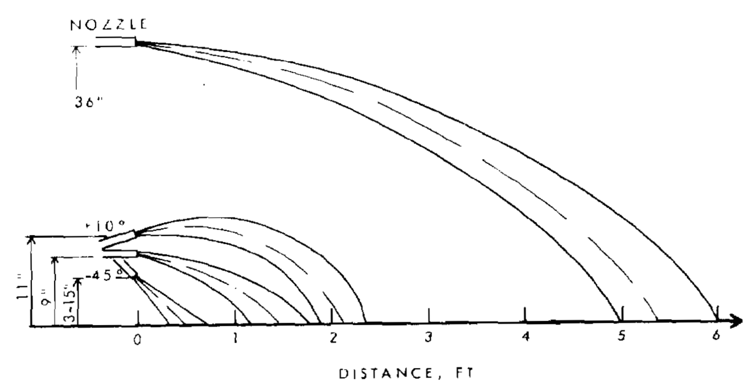

FIGURE 4

POSITIONS OF THE NOZZLE AND PATH OF MATERIAL

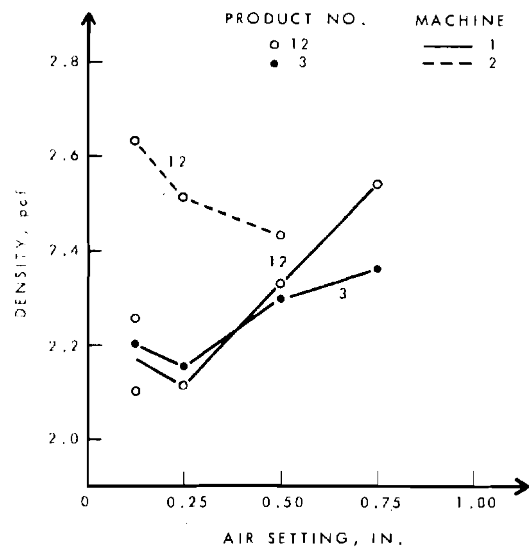

FIGURE 5

DENSITY VERSUS AIR SETTING WHEN BLOWING DOWNWARDS FROM A 6 INCH HEIGHT USING MACHINES 1 AND 2

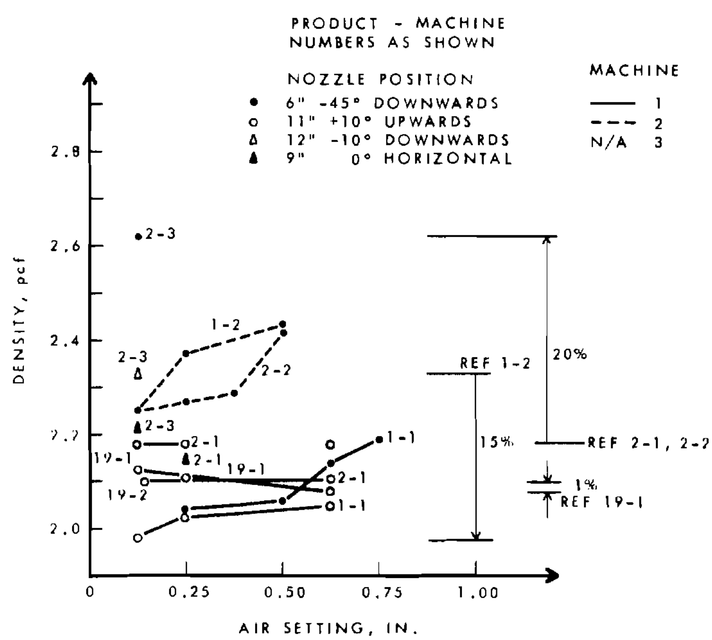

FIGURE 6

DENSITY OF PRODUCTS 1,2 AND 19 DETERMINED WITH MACHINES 1,2 AND 3

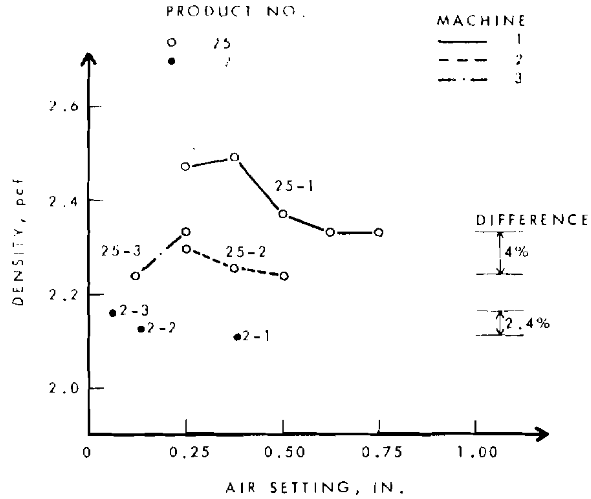

FIGURE 7

DENSITY OF PRODUCTS 25 AND 2 DETERMINED WITH RECOMMENDED BLOWING TECHNIQUE ON MACHINES 1,2, AND 3

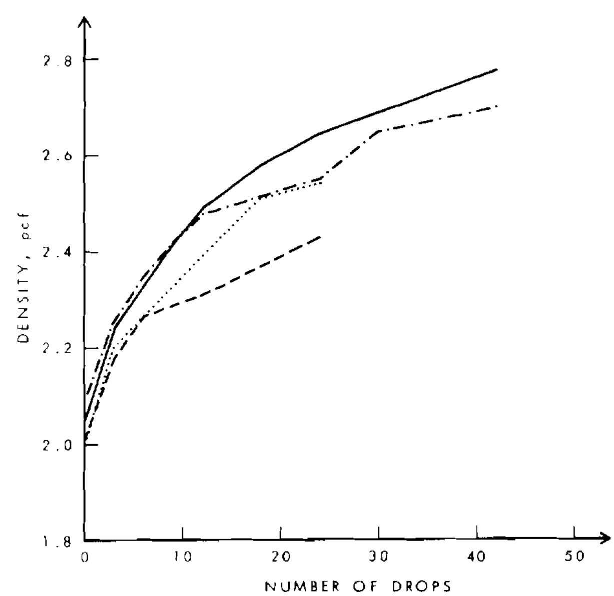

FIGURE 8

DENSITY OF PRODUCT 1 VS NUMBER OF DROPS: FOUR CONTAINERS OF MATERIAL TESTED

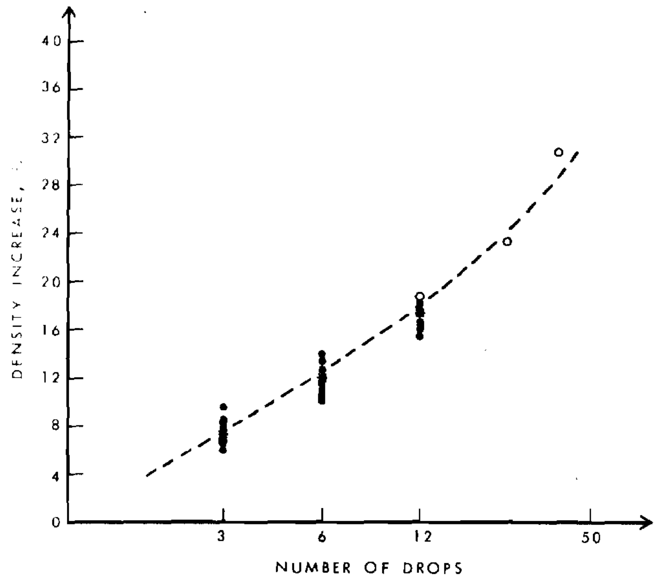

FIGURE 9
INCREASE IN DENSITY DUE TO DROP TEST

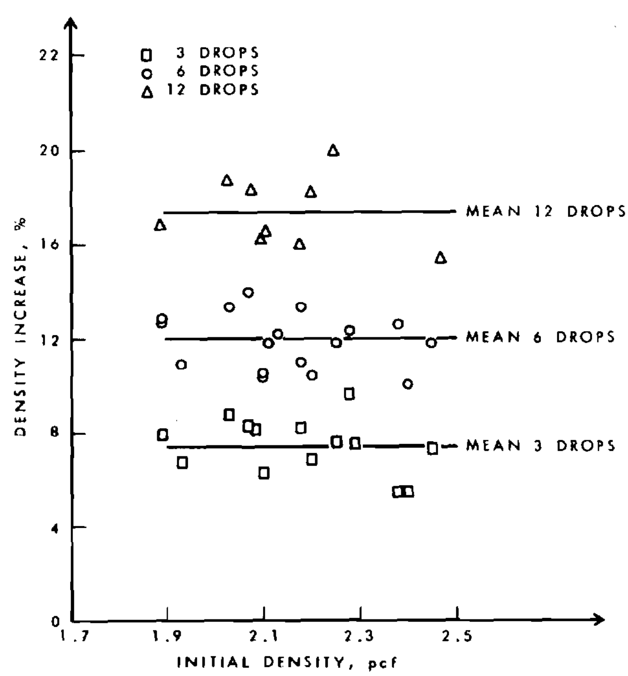

FIGURE 10
EFFECT OF INITIAL DENSITY ON SETTLEMENT DUE TO DROP TEST

APPENDIX A

TEST RESULTS

Table A1 shows the effect of recycling on the density of the blown product.

The same samples were reblown to provide the samples for tests 2, 7, 11 and 13 respectively. The densities of the specimens produced from recycled materials were almost identical to the original densities; the variations were less than 1.5 per cent or 0.03 lb/ft^3. In each case this is well within the standard deviation of 0.04 to 0.11 lb/ft^3.

The importance of size and depth of the container is shown in Table A2. The effect of container dimensions depends on the blowing technique. Results of blowing using two different techniques are shown in Table A2; blowing with the nozzle 11 in. above the bottom of the container and pointed 10 deg upward produces results less influenced by the container dimensions.

Table A3 shows the influence of various air settings and batch variation on the blown density.

Products 10, 19 and 23 were blown using Machine 2 with the nozzle pointed horizontally at a 3-ft height and various air settings.

Changes in the air setting significantly affects the density of the cellulose fiber insulations. With Machine 2, the minimum density was obtained at 1½- and 2-in. air settings. The density of Product 10 varied about 15 percent, but that of Product 19 varied only about 10 percent.

Tests were not made with higher air settings because of excessive dusting. The materials separated and a part of the material fell outside the container. The specimens were not representative of the material.

Tests were performed on material that came from two different production batches of Product 3. The materials for Tests 1 and 12

(Table A1), were obtained several months apart. Their densities differed by about 1.7 percent. The material used in Test 3 (Table A2), was from the same batch as that used in Test 1 (Table A2), but it was taken from different bags and, therefore, a different part of the batch. The densities differed by 6 percent or 0.14 lb/ft^3. This difference is greater than the scatter between tests and indicates that there may be significant variations within production batches.

Results of tests on two batches of Products 19 and 23 are given in Table A3. The densities obtained in Tests 20 and 21 differ by 0.10 to 0.47 lb/ft^3. The densities obtained in Tests 17 and 19 on two batches of Product 19 were 2.27 lb/ft^3 and 3.00 lb/ft^3 when the same blowing conditions were used. The difference was 0.63 lb/ft^3. Further tests with Product 19 in which the blowing conditions were changed produced a density as low as 2.09 lb/ft^3. The larger variations resulted from lack of control over the production process. The difficulties have been solved and later tests show that the density of this product consistently falls between 2.1 and 2.3 lb/ft^3.

Product variability cannot be neglected. It can be reduced by proper design and operation of the plant and persistent quality control.

The results of the tests given in Tables A4 to A7 show the effects of different positions of the nozzle as well as variations in air setting.

The results of the low level blowing with the nozzle at about 6-in. height and pointed toward the surface at about 45 deg are given in Table A4. At certain air settings the density obtained with Machine 1 is the same or even lower than that obtained at the horizontal blowing on 3-ft height (this is referred to as the reference density for a given product). A distance of about 6 in. was found to be optimal for this blowing technique and this machine. Blowing Product 3 downward from a 6-in. height produced an 8 percent lower density than blowing horizontally from a 3-ft level of Tests 29 and 31 (Table A5). The difference was

3 percent for Product 10 in Test 27 and 28 (Table A4). Product 12 did not react in the same way. This may have been due to the variation in the product between different bags of the same batch.

The densities determined with the three different machines are listed in Table A6. Bag-to-bag variations of the products were eliminated from most of the tested materials by recycling them 2 to 4 times. This produced a material that was more uniformly fluffed and allowed a better comparison of the machines.

The three techniques for blowing cellulose fiber, each using a suitable air setting, were compared to see if the same density could be obtained on different machines. Table A6 shows different blowing techniques and three different machines; Table A7 shows different products when using the selected blowing technique and Machine 1. Differences of up to 20 percent for the same material using different blowing machines occurred. These differences can be significantly reduced, however, if the optimum air setting is selected for the given machine.

Table A8 gives some results using the proposed technique. Two products were blown with three machines. For Product 25 the greatest variation in density using the three machines was 4 percent; for Product 2 it was only 2.4 percent. This is much less than the 20 percent difference found for the same product using the other blowing technique. The standard deviation appears to be less than 0.04 lb/ft^3. This method appears to be simple and effective even though it is not the usual way of installing insulation in attics by blowing.

TABLE A1. Effect of recycling on the density of a horizontal layer

Test	Product	Machine	Nozzle Height in.	Nozzle Angle ±degree	Air Setting in.	Container Size in.	Density in containers, lb/ft^3 Container Number 1	2	3	4	Mean	Standard deviation
1	3	2	36	0	-	36x14x4	2.32	2.43	2.29	2.21	-	-
									2.41	2.40	2.34	0.09
2	3r*	2	36	0	-	36x14x4	2.31	2.38	2.40	-	2.36	0.05
6	10	1	36	0	a†	36x14x6	2.07	2.04	2.13		2.08	0.05
7	10r	1	36	0	a	36x14x6	2.15	2.09	2.07	2.13	2.11	0.04
10	12	1	36	0	a	36x14x6	1.89	1.93	1.86		1.89	0.04
11	12r	1	36	0	a	36x14x6	1.90	2.00	1.88	1.84	1.91	0.07
12	3b**	1	36	0	a	36x14x6	2.54	2.38	2.34	2.27	2.38	0.11
13	3br	1	36	0	a	36x14x6	2.46	2.34	2.34		2.38	0.07

*r = recycled sample

**b = different product batch

†a = air setting adjusted to obtain the blowing conditions as specified in provisional specification of Canadian Government Specifications Board Number 51-GP-60P

TABLE A2. Density of a horizontal layer as influenced by the container size.

Test	Product	Machine	Nozzle Height in.	Nozzle Angle ±degree	Air Setting in.	Container Size in.	Density in containers, lb/ft^3 1	2	3	4	Mean	Standard Deviation
1	3	2	36	0	-	36x14x4	2.32	2.43	2.29 2.41	2.21 2.40	2.34	- 0.09
3	3	2	36	0	-	36x14x6	2.51	2.47	2.55 2.43	2.47 2.46	- 2.48	- 0.04
4	3	2	36	0	-	17x17x3	2.37	2.59	-		2.48	-
5	3	2	36	0	-	17x17x6	2.73	2.59	-		2.66	-
6	10	1	36	0	a†	36x14x6	2.07	2.04	2.13		2.08	0.05
8	10	2	36	0	-	17x17x3	2.25	2.03			2.14	-
9	10	2	36	0	-	17x17x6	2.24	2.21			2.22	-
12	3	1	36	0	a	36x14x6	2.54	2.38	2.34	2.27	2.38	0.11
66	10b**	1	11	+10	1/8	11x11x6	1.91	1.94			1.93	-
67	10b	1	11	+10	1/8	11x11x12	1.92	1.95			1.94	-
68	10b	1	11	+10	1/8	36x14x6	1.92	1.93	1.95	1.98	1.95	0.03
69	10b	1	11	+10	1/8	36x14x10	1.92	1.95	1.97		1.95	0.03
70	2r*	1	11	+10	1/8	11x11x6	2.10	2.15			2.12	-
71	2r	1	11	+10	1/8	11x11x12	2.10	2.15			2.12	-
72	2r	2	11	+10	1/8	36x14x6	2.20	2.20	2.23	2.24	2.22	0.02
73	2r	1	11	+10	1/8	36x14x10	2.23	2.25	2.25		2.24	0.01

**b = different product batch

*r = recycled sample

†a = air setting adjusted to obtain the blowing conditions as specified in provisional specification of Canadian Government Specifications Board Number 51-GP-60P

TABLE A3. Influence of various air settings and batch variation on density of a horizontal layer

Test	Product	Machine	Nozzle Height in.	Nozzle Angle ±degree	Air Setting in.	Container Size in.	Density in containers, lb/ft^3 1	2	3	4	Mean
14	10	2	36	0	0	36x14x4	2.11	2.21			2.16
					1/4		2.00	2.04			2.02
					3/8		1.93	2.03			1.98
					1/2		1.87	1.94			1.90
					1		1.82	1.89			1.86
17	19	2	36	0	3/8	36x14x4	2.23	2.31			2.27
					1		2.06	2.15	2.18		2.13
					1 1/2		2.11	2.10	2.06		2.09
					2		2.15	2.12			2.13
19	19b**	2	36	0	3/8	36x14x4	2.96	3.02	2.89	3.12	-
									3.00	3.01	3.00
20	23	2	36	0	1/4	36x14x4	3.29				3.29
					1		3.00				3.00
					1 1/4		3.00	2.40			2.70
					1 1/2		2.98	2.19	2.71	2.71	-
									2.63	2.57	2.63
21	23b	2	36	0	3/8	36x14x4	2.19	2.63	2.71	2.71	-
									2.57	2.40	2.53
22	4	2	36	0	-	36x14x4	1.80	1.62	1.57		1.66

**b = different product batch

TABLE A4. Density of a horizontal layer as influenced by hose position

Test	Product	Machine	Nozzle Height in.	Nozzle Angle ±Degree	Air Setting in.	Container Size in.	Density, lb/ft^3 1	2	3	4	Mean
15	10	2	6	-45	1/8	36x14x6	1.99				1.99
16	10	2	15	-45	3/8	36x14x6	2.18				2.18
18	19	2	3	-45	1/8	36x14x4	2.19	2.15			2.17
					1/4		2.13	2.13			2.13
23	4	2	6	-45	0	36x14x4	1.97	1.94	1.96		1.96
24	12	1	6	-45	3/4	36x14x4	2.54				2.54
					1/2		2.33				2.33
					1/4		2.11				2.11
					1/8		2.10				2.10
25	12	1	3	-45	1/8	36x14x4	2.41				2.41
26	12	2	6	-45	1/8	36x14x6	2.63				2.63
					1/4		2.51				2.51
					1/2		2.43				2.43
27	10b**	1	36	0	3/4	36x14x6	2.15	2.09	2.07	2.13	2.11
28	10b	1	6	-45	1/8	36x14x4	2.13	1.95	2.13	2.00	2.05

**b = different product batch

Table A5

Effect of air setting and position of the nozzle on density.

Container size 36x14x6 in.

Test	Product	Machine	Nozzle		Air setting in.	Density in containers, lb/ft^3					
			Height in.	Angle ±degree		1	2	3	4	Mean	Stand. Deviation
29	3	1	36	0	3/4	2.54	2.38	2.34	2.27	2.38	0.11
30	3		6	-45	1/8	2.46	2.36	2.44	2.52	2.45	0.07
31	3		6	-45	1/8	2.11	2.24	2.21	2.23	2.20	0.06
					1/4	2.15				2.15	-
					1/2	2.30				2.30	-
					3/4	2.36				2.36	-
33	12		36	0	3/4	1.90	2.00	1.88	1.84	1.91	0.07
34	12		6	-45	1/8	2.18	2.10	2.08	2.16	2.13	0.05
35	12		6	-45	1/8	2.10	2.41	2.31	2.33	2.28	0.12
					1/8	2.26					

Table A6

Density of specimens produced by different blowing machines

with different air settings

container size 36x14x6 in.

Test	Product	Machine	Nozzle Height in.	Nozzle Angle ±deg.	Air setting in.	Density in containers, lb/ft^3 1	2	3	4	Mean	Standard Deviation
37	2	2	36	0	1/4	2.23	2.18	2.14	2.18	2.18	0.04
39	2	3	36	0	1/16	2.19	2.18	2.14	2.21	2.18	0.03
40	2	2	6	-45	1/8	2.25				2.25	-
					1/4	2.16	2.27	2.29	2.35	2.27	0.08
					3/8	2.29				2.29	-
					1/2	2.42				2.42	-
41	2	3	6	-45	1/8	2.58	2.79	2.51	2.58	2.62	0.12
42	2r*	3	12	-10	1/8	2.39	2.27	2.30	2.35	2.33	0.05
38	2r	3	9	0	1/16	2.20	2.16	2.22	2.26	2.21	0.04
44	1	1	6	-45	1/4	2.05	2.00	2.01	2.09	2.04	0.04
					1/2	2.06				2.06	-
					5/8	2.14				2.14	-
					3/4	2.19				2.19	-
45	1r	2	6	-45	1/8	2.29	2.28	2.19	2.22	2.25	0.05
					1/4	2.37				2.37	-
					1/2	2.43				2.43	-
46	1	2	36	0	3/4	2.43	2.43	2.33 2.23	2.25 2.29	2.33	0.08
32	3r	2	6	-45	1/8	2.34	2.27	2.29	2.31	2.30	0.03
36	12r	2	6	-45	1/4	2.51	2.43	2.45	2.54	2.48	0.05
48	19	1	36	0	3/4	2.11	2.10	2.06	2.06	2.08	0.03
49	19	2	6	-45	1/8	2.07	2.11	2.06	2.14	2.10	0.04

*r = recycled sample

TABLE A7

Effect of angle and height of nozzle on the density
Container size 36x14x6 in.

Test	Produce	Machine	Nozzle Height in.	Nozzle Angle ±degree	Air Setting in.	Density in containers, lb/ft^3 1	2	3	4	Mean	Standard Deviation
51	2	1	6	-45	1/8	2.06	2.07	2.15	2.06	2.09	0.04
55	2	1	6	-45	1/4	2.13				2.13	-
56	2	1	9	0	1/4	2.15				2.15	-
54	2r*	1	9	0	1/8	2.06	2.09	2.08		2.08	0.02
57	2r	1	11	+10	1/8	2.12	2.11	2.14	2.02	2.10	0.05
58	2r	1	11	+10	3/8	2.07	2.11	2.11	2.14	2.11	0.03
52	2r	1	11	+10	3/8	2.09				2.09	-
53	2r	1	11	+10	1/8	2.08				2.08	-
59	2r	1	11	+10	3/8	2.18	2.18			2.18	-
43	2r	1	11	+10	1/4 1/8	2.16 2.17	2.19 2.18			2.18 2.18	- -
50	19r	1	11	+10	1/8 1/4 3/8	2.02 2.11 2.08	2.11	2.17	2.17	2.12 2.11 2.08	0.07
45	1r	1	11	+10	1/8 1/4 3/8	1.98 2.03 2.05	1.97	1.99	1.96	1.98 2.03 2.05	0.01 - -

*r = recycled sample

Table A8

Density produced using the proposed blowing technique on three machnes.

The same sample of material was used for each set of tests.

Test	Product	Machine	Air setting in.	Density in containers lb/ft^3					
				1	2	3	4	Mean	Standard Deviation
60	25	1	1/4	2.47				2.47	
			3/8	2.49				2.49	
			1/2	2.37				2.37	
			5/8	2.29	2.36	2.33	2.34	2.33	0.03
			3/4	2.33				2.33	
61	25r*	2	1/4	2.30				2.30	
			3/8	2.23	2.25	2.25	2.30	2.26	0.03
			1/2	2.24				2.24	
62	25r	3	0.5H2***	2.33				2.33	
			0.3H2	2.21	2.21	2.26	2.26	2.24	0.03
63	2r	1	3/8	2.07	2.11	2.11	2.14	2.11	0.03
64	2r	2	1/8	2.16	2.12	2.12	2.13	2.13	0.02
65	2r	3	0.2H2	2.20	2.14	2.11	2.19	2.16	0.04

*r = recycled sample

***H2 = second air setting hole

TABLE A9

Density before and after dropping from 6 in. height
Each figure represents mean of 3 or 4 36x14x6 in. containers

Test Number	Product Number	Density as blown	3 drops		6 drops		12 drops	
			Density	%change	Density	%change	Density	%change
1	1	2.03	2.21	8.7	2.30	13.3	2.41	18.7
2	2	2.18	2.36	8.2	2.57	13.3	-	
3	2	2.28	2.50	9.6	2.56	12.3	-	
4	2	2.47	-		-		2.85	15.4
5	3	2.08	2.25	8.1	-		2.46	18.3
6	3	2.10	-		2.32	10.5	2.44	16.2
7	3	2.18	-		2.42	11.0	2.53	16.0
8	3	2.20	2.35	6.8	2.43	10.4	2.60	18.2
9	3	2.40	2.53	5.4	2.64	10.0	-	
10	3	2.38	2.51	5.4	2.68	12.6	-	
11	3	2.45	2.63	7.3	2.74	11.8	-	
12	10	1.89	-		2.13	12.7	2.21	16.9
13	10	2.07	2.24	8.2	2.36	14.0	-	
14	10	2.10	2.23	6.2	2.34	11.4	-	
15	12	1.89	2.04	7.9	2.13	12.7	-	
16	12	1.93	2.06	6.7	2.14	10.9	-	
17	12	2.13	2.29	7.5	2.39	12.2	-	
18	12	2.25	2.43	7.6	2.55	11.8	2.70	20.0
19	19	2.11	-		2.36	11.8	2.46	16.6
		mean		7.4		11.9		17.4
		stand. deviation		1.2		1.1		1.5