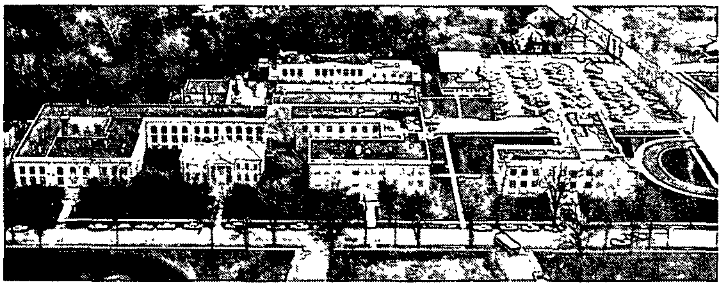

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

IPC TECHNICAL PAPER SERIES

NUMBER 177

IMPULSE DRYING: A PERFORMANCE OVERVIEW

C. H. SPRAGUE

MAY, 1986

IMPULSE DRYING: A PERFORMANCE OVERVIEW

C. H. Sprague
Director, Engineering Division
The Institute of Paper Chemistry
P.O. Box 1039
Appleton, WI 54912

ABSTRACT

When a well-pressed but moist sheet of paper or board is passed through a high temperature press nip, water is removed by three primary mechanisms: thermally-augmented wet pressing, thermally induced liquid phase dewatering, and intense evaporation. The result is an extremely rapid dewatering process called impulse drying. Impulse drying uses less than half the energy of a conventional dryer, removes water 1000 times faster, and produces exceptional densification and bonding, even with difficult to bond furnishes. This paper presents a performance overview for the impulse drying process, based on bench-scale laboratory tests. Water removal rates, energy efficiency, and property data for a range of conventional and exploratory furnishes and grades are all described.

INTRODUCTION

In papermaking, the last small bit of water in the wet paper web is removed first by pressing and then by drying or evaporation. Wet-pressing, usually carried out at relatively low web temperatures, removes water by purely mechanical means. Hot pressing (1) utilizes higher web temperatures to incrementally improve pressing performance, but the fundamental water removal mechanisms remain unchanged. Conventional drying, in contrast, removes water purely by evaporation. For this common mode of operation, web consolidation, i.e., sheet densification, is achieved primarily in the press and captured or "set" in the dryer. Desirable properties such as stretch or controlled shrinkage may actually be lost in the dryer, but in any event the dryer does not have a large or controllable positive impact on properties.

In an earlier paper, Sprague and Burton (2) suggested that additional improvements based on current pressing and drying technologies are likely to be small because of the fundamental limitations imposed on these processes. They further suggested that new processes involving new or much more intense driving forces are required for substantially better web consolidation performance. One such process is impulse drying.

Impulse drying is a name coined for the process of removing water from an already well pressed but moist paper web in a very hot press nip. First suggested by Wahren (4) in the late 1970's, the process received little additional development until about 1981 when exploratory work was initiated by The Institute of Paper Chemistry. Some of this early work was described by Ahrens (5) and by Arenander and Wahren (6).

Impulse drying generally involves pressures of 0.3-7 MPa, temperatures from 150-500°C, and exposure times up to 100-150 ms. This combination of intense, short duration conditions gives rise to dewatering and densifying mechanisms never before encountered in papermaking. These mechanisms are identified and discussed in general terms in Sprague and Burton (1). A subsequent paper (3) will treat them in much more detail. The purpose of this paper is to briefly review these mechanisms and illustrate the extraordinary performance they lead to.

EXPERIMENTAL

Impulse Drying Presses

Early experimental work on impulse drying has been carried out on wet pressing simulators with one pressing surface at an elevated temperature. For exposure times less than about 10 ms a falling-weight simulator (sometimes called a

Wahren-Zotterman or hammer and anvil simulator) is used (7). For longer times, an electrohydraulic press (MTS) with an electronically controlled pressure-time profile is used. Finally, a simple roll press is operated at various speeds to produce nip residence times from a few milliseconds to several hundred milliseconds. All three presses can produce the typical bell-shaped pressure-time profile of a roll press; only the electrohydraulic press can produce more arbitrary profile shapes including the nearly rectangular pulse of the extended nip. This electrohydraulic unit, now the workhorse for laboratory studies of impulse drying, is shown in Fig. 1. Instrumentation in the heated platen includes a vapor pressure transducer and a surface thermocouple used for temperature control and to provide the measurements necessary for heat flux calculations. A load cell above the upper platen is used to control and measure the total load profile. External electronics provide for automatic sequencing of the system for a drying test. Not shown in the figure is a ring presteamer for heating the sheets prior to impulse drying.

Handsheets

Handsheets are made according to TAPPI standard procedures except for size, which has been reduced to 5" to permit high pressure drying within the dynamic force limits of the MTS system. Sheets are couched and lightly pressed to a high moisture content and stored in sealed plastic bags in cold conditions. Storage time is limited to one or two days. Just prior to drying, the sheets are prepressed to the desired moisture content in a roll press using impulse values typical of commercial practice. This pressing procedure is not standard for handsheets, but is used to avoid undue densification in the pressing step.

Impulse Drying

After prepressing, the sheets are weighed and placed on a fresh, dry wet pressing felt on the lower platen. The upper platen is then lowered automatically to contact the sheet and deliver the desired pressure profile. Impulse drying is usually used to remove only a part of the water originally in the sheet. Thus, immediately after impulse drying, the sheet is again weighed and then dried to about 6% moisture between a dryer felt and a flat plate. This conventional drying simulator operates at a contact pressure of about 3.5 KPa and a temperature of 115°C. Precalibration is used to establish the necessary drying time for a given impulse drying condition so the desired final moisture target can be reached without over-drying.

Once they have been dried to 6% moisture content, the handsheets are conditioned as required by TAPPI standards and subjected to a full battery of property tests. A basic set of properties is measured on all grades; in addition, each grade is subjected to tests specifically appropriate to that grade. Remnants from the tests are oven dried to get the dry fiber weight required for the water removal calculations.

Control Sheets

To provide control conditions for reference, a few handsheets from each set are treated exactly as for impulse drying except the impulse drying step is omitted. These sheets are dried entirely on the conventional drying simulator. Hence, the data presented subsequently in this paper accurately reflect the incremental effect of removing a part of the water remaining in the sheet after pressing by the impulse drying process. Figure 2 shows a flow chart for the experimental test procedure used to evaluate impulse drying.

Furnishes

Several standard grades which represent a large proportion of total USA production have been selected for use in an initial limited evaluation of the impulse drying process. These include linerboard base stock, both virgin and recycled fiber; a corrugating medium furnish; newsprint; a writing grade; a lightweight coating stock; tissue; recycled boxboard; and a special high yield furnish. Each grade has been tested under a range of impulse drying conditions. Excerpts from this overall evaluation experiment will be presented in this paper to highlight the performance of the impulse drying process.

Impulse Dryer Performance Measures

Impulse dryer performance is measured in terms of total water removal or water removal rate, specific energy use and paper property development. Total water removal and water removal rates are determined directly from the measurements of pre and post sheet weights. Separate chemical tracer techniques are sometimes used to determine the amount of liquid dewatering produced by impulse drying. The heat flux to the sheet is determined from the heated platen surface temperature-time history and an appropriate heat conduction model for the platen. Total heat transfer determined as the time integral of the heat flux is used to get specific energy consumption, i.e., energy used per unit of water removed.

IMPULSE DRYING PERFORMANCE

Water Removal

By definition, impulse drying involves dewatering under very intense, short duration conditions. It is, therefore, important to maximize water removal rates to keep equipment sizes as small as possible. Also, it has already been shown (8) that much of the total water removal occurs in liquid form. Maximizing the liquid fraction of the removal is essential to total water removal performance and to minimizing specific energy consumption. There are, thus, two primary measures of water removal performance: water removal rate and the fraction of water removed as liquid.

Water removal rates. As expected for this very intense process, average water removal rates are extremely high, ranging between those for wet pressing and conventional drying. Regardless of grade or basis weight, the values tend to range up to several thousand kg/hr/m^2. These values are as much as 1000 times greater than those for cylinder drying at 25 kg/hr/m^2. Data for typical impulse conditions for a linerboard basesheet (virgin kraft, CSF = 670) and newsprint (20% kraft, 80% GW, CSF = 115 mL) are shown in Fig. 3. For perspective, the newsprint sheet can be "dried" from 50% solids to 85-90% solids in 20-25 ms, i.e., in a single impulse nip.

It is noted that water removal rate is a strong, essentially linear function of hot surface temperature divided by the square root of nip residence time. This somewhat curious independent variable, selected primarily because it describes well the behavior of the process, may make some sense in light of the dominance of Darcy's law flow in the process. Nip pressure is only a modestly influential variable, at least over the range tested thus far, 1-5 MPa.

Multiple linear correlations for these grades are as follows:

Linerboard $\mathrm{WRR} = -750 + 133P + 83.8\ \mathrm{TEMP}/\sqrt{\mathrm{NRT}} \quad R^2 = 0.96$

Newsprint $\mathrm{WRR} = -30.6 + 110P + 56.9\ \mathrm{TEMP}/\sqrt{\mathrm{NRT}} \quad R^2 = 0.95$

Other grades follow similar patterns and dewater at similar rates.

Fast water removal requires high temperature, high pressure and a short nip. Total water removal, however, increases with nip time, as expected. As we shall show later, these same variables affect density, but in a somewhat different way, so there is opportunity for tradeoffs between density development and water removal in the selection of impulse drying conditions.

As the data show, impulse drying from one side of the sheet does not diminish the ability to dewater from the opposite side. Most grades will require two sided drying for property balance. Also, the water removal rate tends to vary directly with ingoing moisture content so wetter sheets dewater more rapidly. As a result, outgoing moisture content is a fairly weak function of ingoing moisture content, reflecting about the same degree of moisture profile leveling as in wet pressing. This is an important advantage in that it extends this leveling ability into the solids range normally reserved for cylinder drying, which has little leveling ability.

Liquid dewatering. Liquid dewatering in impulse drying is apparently caused by a thermally augmented wet pressing effect and by displacement or entrainment of liquid water by bulk vapor flow. These mechanisms suggest a strong and positive influence of hot surface temperature, which is indeed reflected in the data. Both tracing chemicals and energy balances have been used to estimate the liquid fraction of the water removed. These independent measures are in generally good agreement and produce the type of data shown in Fig. 4. As indicated, the liquid fraction increases linearly with hot surface temperature and may range up to 40% or more for some drying situations. It should be noted that this is liquid water being removed from a sheet that has already been well pressed.

Effect of preheating. All of the data presented thus far were obtained from sheets initially at room temperature. It is expected, however, that an impulse dryer would be installed after a good press section, where the sheet temperature is likely to be elevated. Furthermore, the basic mechanisms of impulse drying (1) suggest that preheating of the moist web to near the ambient boiling point would be beneficial. The data in Fig. 5 show that this is true. Preheating to about 100°C raised the total water removal from about 35% up to near 56%, an increase in total dewatering of 60%. Almost all of the increase occurred as liquid dewatering, thus substantially reducing the amount of evaporation required. It thus appears highly desirable to use low grade thermal energy as a preheating medium to increase overall water removal and decrease the specific use of high grade thermal energy.

Energy Consumption

In impulse drying, energy is used to sensibly heat the fiber and water, and to evaporate water. Because of the large latent heat of water, evaporation dominates the energy use picture, limited by the fraction of water removed in liquid form. Specific energy use values have been estimated from heat conduction models and surface temperature measurements for the heated platen and from sheet energy balances based on experimental measurements of total and liquid dewatering. Both are in reasonable agreement, as indicated in Fig. 6. Also shown in Fig. 6 is an energy transfer estimate based on a purely evaporative drying process at the given surface temperature.

Specific energy consumption in impulse drying decreases with surface temperature, a reflection of increasing liquid phase dewatering, as noted earlier. In this range the data suggest slightly less specific energy use in the longer nip, a reflection of the more effective use of sensible heating. Preheating the web dramatically reduces specific energy consumption by reducing the sensible heating component and by increasing the liquid phase dewatering fraction. Overall, without preheating (room temperature webs) impulse drying will use approximately half as much energy as a cylinder dryer; with preheating, the ratio will drop to one third, not including the energy for preheating. Although impulse drying offers a large specific energy advantage, the availability and low cost of low pressure process steam are duly noted.

Property Development

Usually the water remaining after pressing is removed slowly by a gentle, purely evaporative process. In impulse drying, the water is removed very rapidly, partially as a liquid and partially as vapor. At the same time, the sheet is under considerable transverse and longitudinal restraint, altering the normal shrinkage and drying stress patterns (8) that accompany cylinder drying. Finally, at least one side of the sheet is in intimate contact with a smooth, hot surface. Collectively, these new and intense dewatering and densifying mechanisms result in paper physical properties that are very different from those attained in conventional drying.

Densification and strength. Impulse drying results in high average density values, even for small amounts of water removal, and in very nonuniform Z-direction density profiles. For linerboard base stock, increases in average density* of over 40% have been observed for short duration one-sided impulse drying, Fig. 7. For two-sided impulse drying at modest conditions, a density increase of 56% was achieved. Longer or more intense drying would produce still

---

*All densities cited in this paper are IPC density values obtained by using the IPC rubber platen caliper gage (9). These values will be slightly higher than TAPPI densities but are believed to more accurately reflect the structural properties of the sheets.

higher density. As noted from Fig. 7, density is well related to pressing pressure and to thermal impulse (area under temperature-time curve). In this relationship thermal impulse is the most important variable, but pressure plays an important independent role. Low pressures may limit the ability of thermal impulse to produce density, Fig. 7.

All grades show similar densification behavior, but highly beaten grades respond more slowly, apparently because they already have a high bonding potential. For stocks that are normally difficult to bond, such as recycled fiber or some high yield furnishes, impulse drying produces excellent densification, often bringing these furnishes into competition with low yield kraft for strength development. Figure 8 illustrates this behavior for a recycled linerboard stock based on old corrugated containers and for a high yield experimental chemimechanical pulp. Both furnishes respond poorly to conventional processing, as illustrated by the densities obtained under control conditions, but readily densify and develop strength under impulse drying conditions. Both furnishes dewater readily as well, making impulse drying an ideal consolidation process for these low cost furnishes.

Strength properties. Increases in strength usually accompany increases in density, often in a nearly linear form for conventional processing (10). This is a direct reflection of the close tie between bonding and density. Similar relationships tend to remain valid for impulse drying, as well, as illustrated in Fig. 8 and 9. Hence, the high density values from impulse drying lead directly to high strength values. The STFI compressive strength of the linerboard base sheet, impulse dried on two sides, was almost 40% above that for the control sheet. Most other strength properties such as tensile and burst increase correspondingly, whereas tear, as expected, is reduced, as shown in Fig. 10. Surprisingly, stretch remains largely unaffected by impulse drying.

Density, as developed by impulse drying, is as effective in producing strength as is the density developed by wet pressing. This is illustrated directly by Fig. 9 and indirectly by the data cited above. The ability of impulse drying to promote bonding, even for poorly bonding furnishes, is illustrated in Fig. 8 by the performance comparison of three furnishes: virgin linerboard, recycled linerboard, and the 75% yield CMP, all processed identically. This graph is perhaps most indicative of the true potential of impulse drying to reduce raw material costs.

Optical properties. Brightness and opacity tend to be reduced slightly by impulse drying, especially for high levels of water removal. For well bleached furnishes, the optical properties loss may be 2-3 percentage points. For furnishes with higher lignin contents such as newsprint, the losses may increase to 4-5 percentage points, especially for high degrees of impulse drying. Typical results for a lightweight coating stock (47% bleached softwood kraft, 53% TMP) are shown in Fig. 11, plotted versus sheet density.

Other properties. Many other properties of paper are significantly influenced by impulse drying as well. Some of these are briefly described below. Unless otherwise specified, properties were measured on the side of the sheet next to the hot surface.

> Surface roughness - reduced by 40-60% depending on the furnish and the amount of water removed. Felt side roughness tends to remain constant or increase slightly from felt imprinting. For two-sided impulse drying smoothness is improved on both sides.

Absorbency and ink penetration - both are reduced substantially. For the lightweight coating stock, the water absorption time increased by a factor of 6-7 when the solids content of the sheet was raised from 50 to 75% by impulse drying. Ink penetration times increased by 20-30%.

Air permeability - air permeability decreases steadily with increasing water removal. For the lightweight coating grade, permeability dropped from 620 mL/min for the control sheet to about 130 mL/min for a sheet impulse dried to 81% solids.

Pick resistance - all furnishes showed great resistance to picking or peeling, often double those for the control sheet. As a consequence, impulse dried sheets should be very resistant to dusting, scuffing, linting or peeling, an important consideration for some grades.

SUMMARY

Impulse drying is a dramatic new process for dewatering or drying paper and perhaps other porous, compressible webs, as well. It embodies a number of new and very intense dewatering and densifying mechanisms. These lead to dewatering rates 100-1000 times those for cylinder dryers, specific energy levels of 1/3 to 1/2 those for conventional drying, and a tremendous capacity for promoting web consolidation and strength. Other properties are often improved as well. The degree of improvement generally varies directly with the amount of water removed. Conventional furnishes may actually be overdensified by impulse drying allowing substitution of lower cost furnishes to achieve equivalent end-use performance.

Impulse drying is based on pressing technologies currently in operation. High temperature operation of one pressing surface, the new ingredient required to produce impulse drying performance, raises some new engineering questions, but none seems unanswerable. Hence, it appears that impulse drying is a practical process with excellent potential for lowering costs, improving properties, or adding incremental capacity. A major project, now underway with the support of the U.S. Department of Energy, is designed to produce the data base necessary for the commercial application of the process.

ACKNOWLEDGMENTS

The work reported in this paper was supported by the members of The Institute of Paper Chemistry. Excellent experimental help was provided by James Loughran and Lester Nett. Some of the early exploratory work was directed by Dr. Fred Ahrens, who is no longer at the Institute. All of these sources of support and help are gratefully acknowledged.

REFERENCES

1. Anderson, L., and Back, E., Proceedings TAPPI Engineering Conference, p. 311-323, 1981.
2. Sprague, C. H., and Burton, S., Proceedings of International Conference - New Technologies in Web Consolidation and Drying, May 19-23, 1986, (in press).
3. Burton, S., Sprague, C., and Ahrens, F., Fifth International Drying Symposium (IDS '86), Aug. 13-16, 1986, (in press).
4. Wahren D., U.S. Pat. 4,324,613 (April 13, 1982).
5. Ahrens, F. W., Proceedings of the 45th Executives' Conference, May 1-7, 1981, The Institute of Paper Chemistry, Appleton, WI, p. 21.
6. Arenander, S., and Wahren, D., Tappi 66(9):123(1983).
7. Zotterman, C., and Wahren, D., Paper Trade J., 162(16):37, 64(1978).

8. Htun, M., and de Ruvo, A., _Trans. of the BPBIF Symposium on Fiber - Water Interactions in Papermaking_, held at Oxford, Sept. 1977.

9. Wink, W. A., and Baum, G. A., _Tappi_ 66(9):131-133(1983).

10. MacLaurin, D. J., and Whalen, J. F., _Tappi_ 37(12):608(1954).

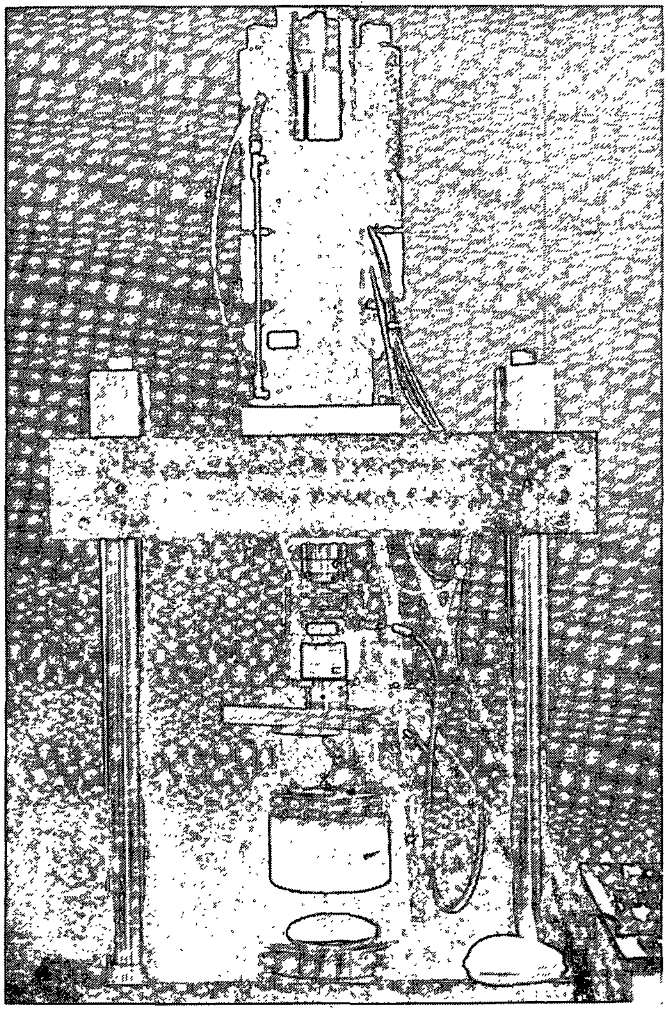

Figure 1. MTS electrohydraulic press nip simulator with impulse drying head installed.

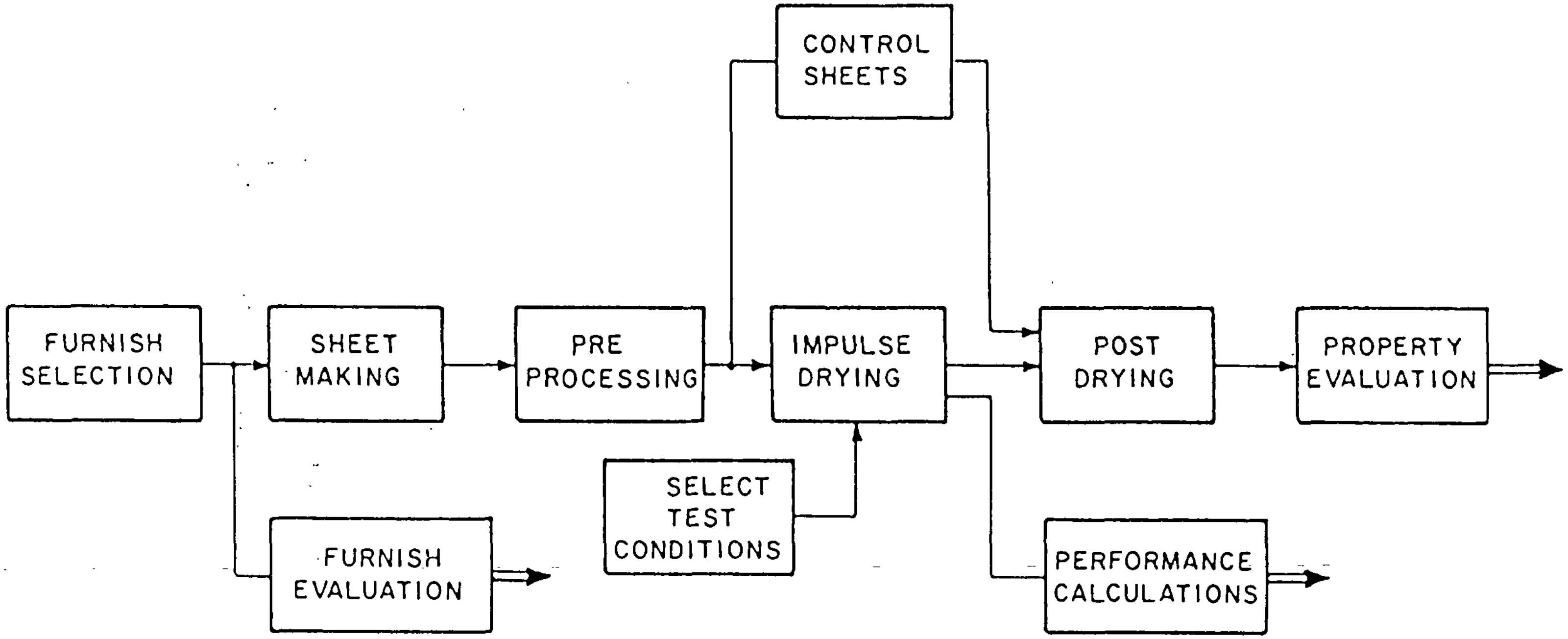

Figure 2. Elements of performance evaluation.

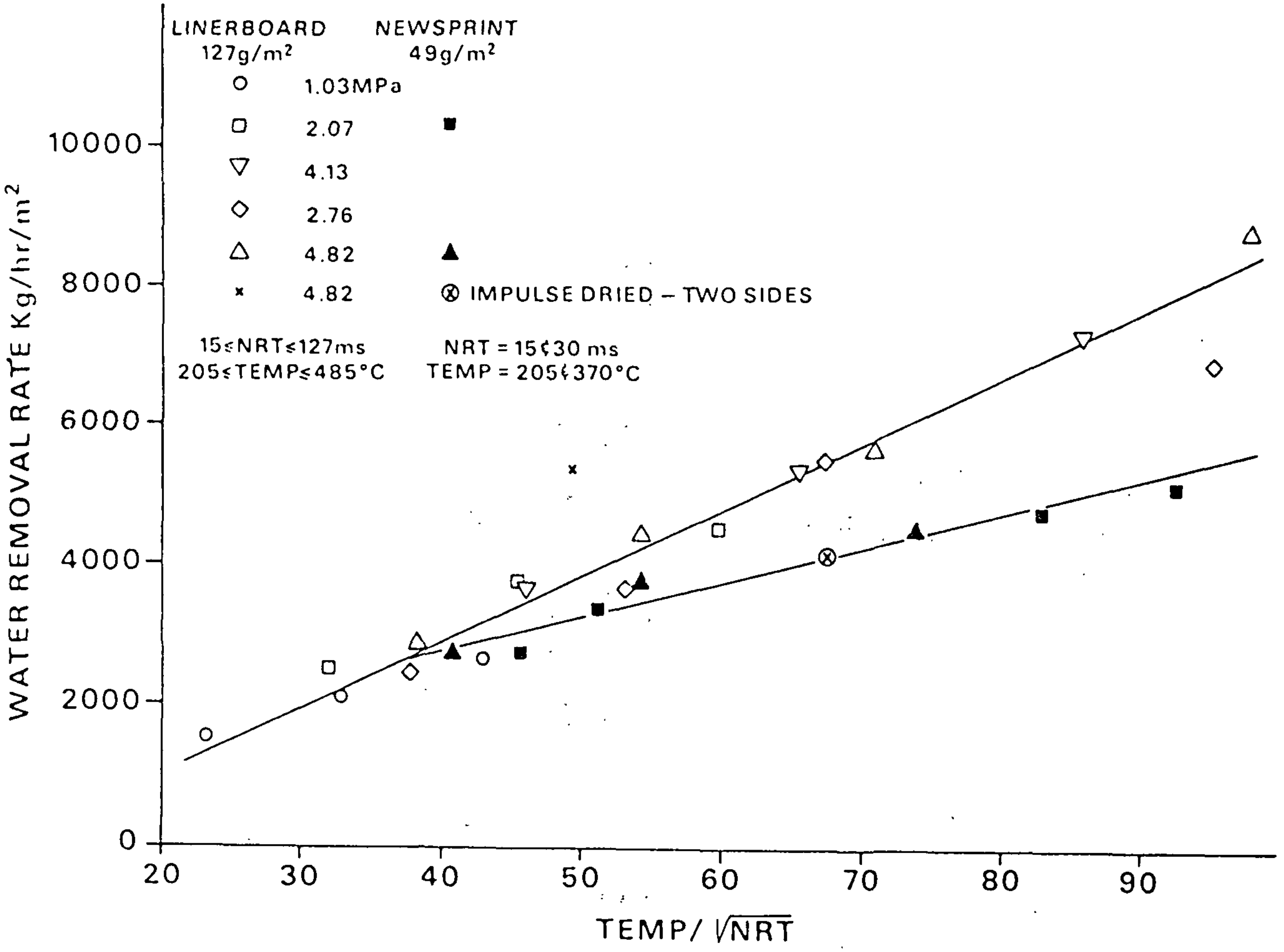

Figure 3. Water removal rates for virgin linerboard base stock and newsprint.

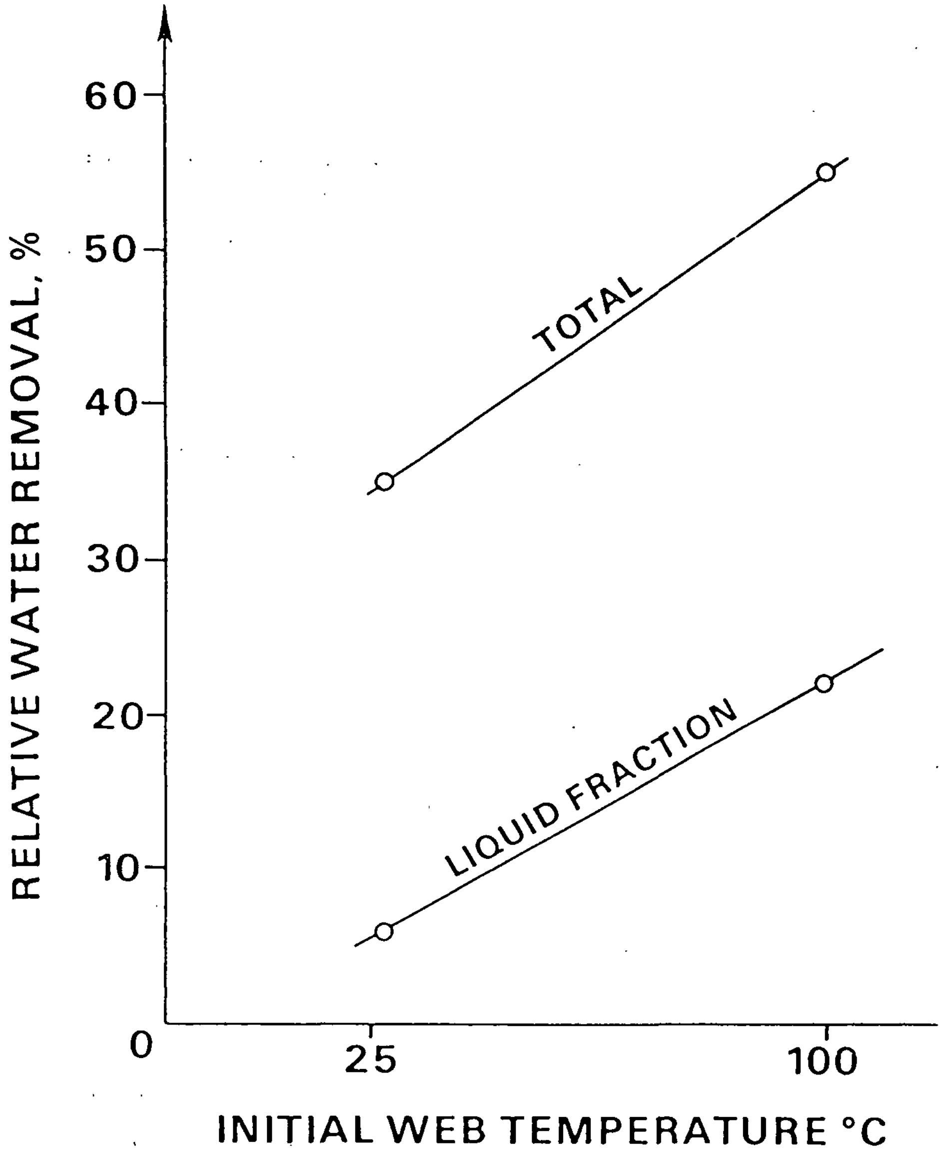

Figure 5. Effect of web preheating on total and liquid fraction water removal.

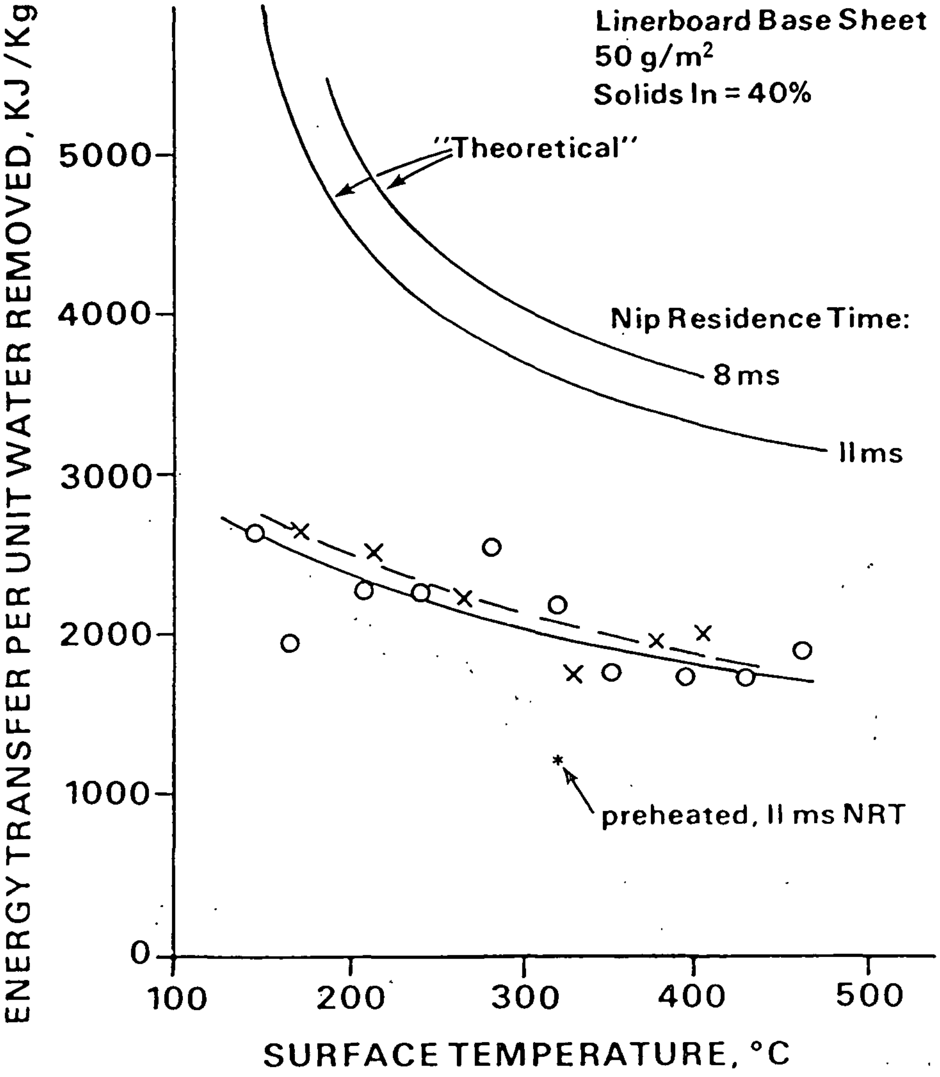

Figure 6. Theoretical heat input for pure evaporation process and actual heat input for impulse drying. x = 8ms, 0 = 11ms.

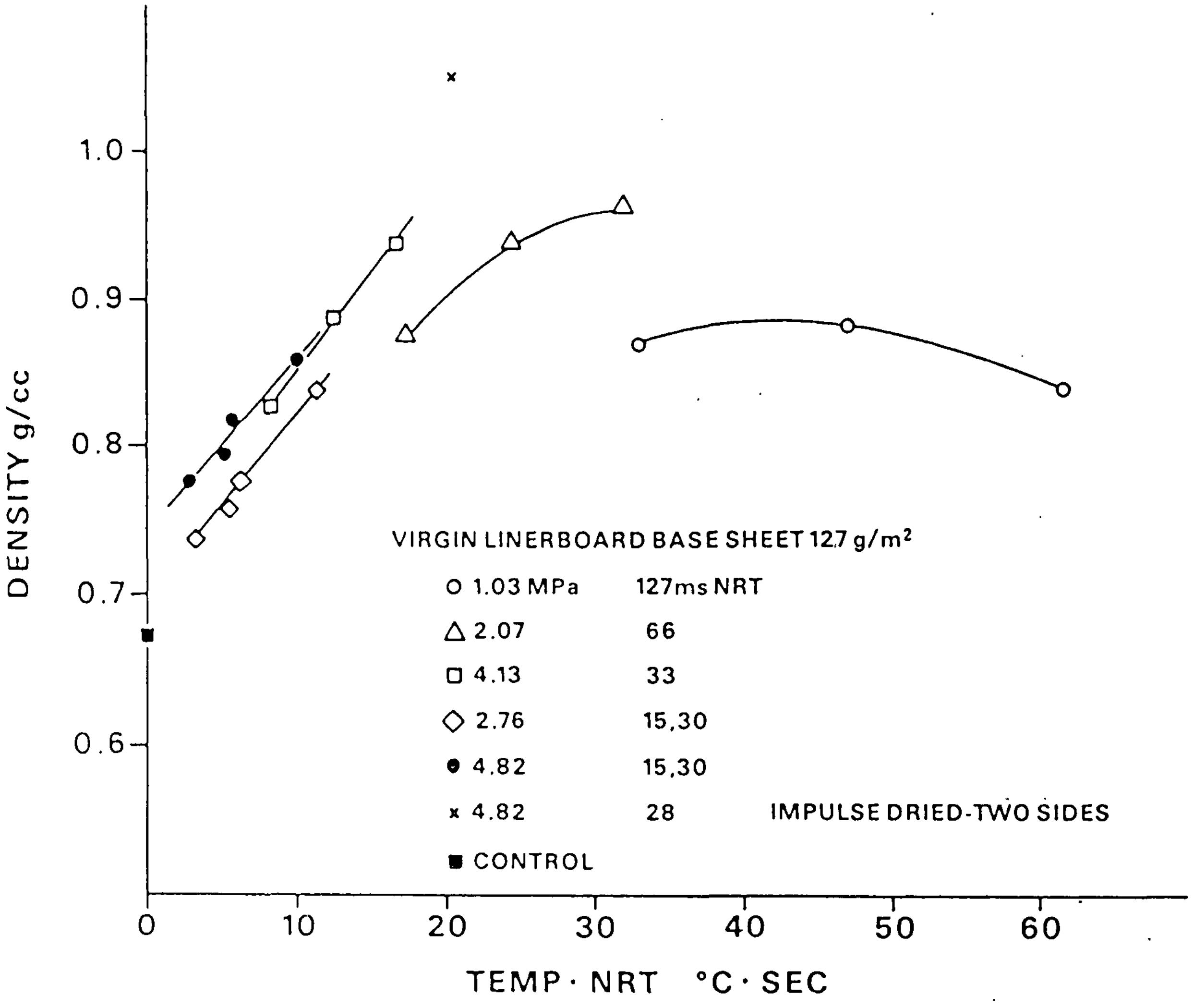

Figure 7. Density development for virgin linerboard base sheet.

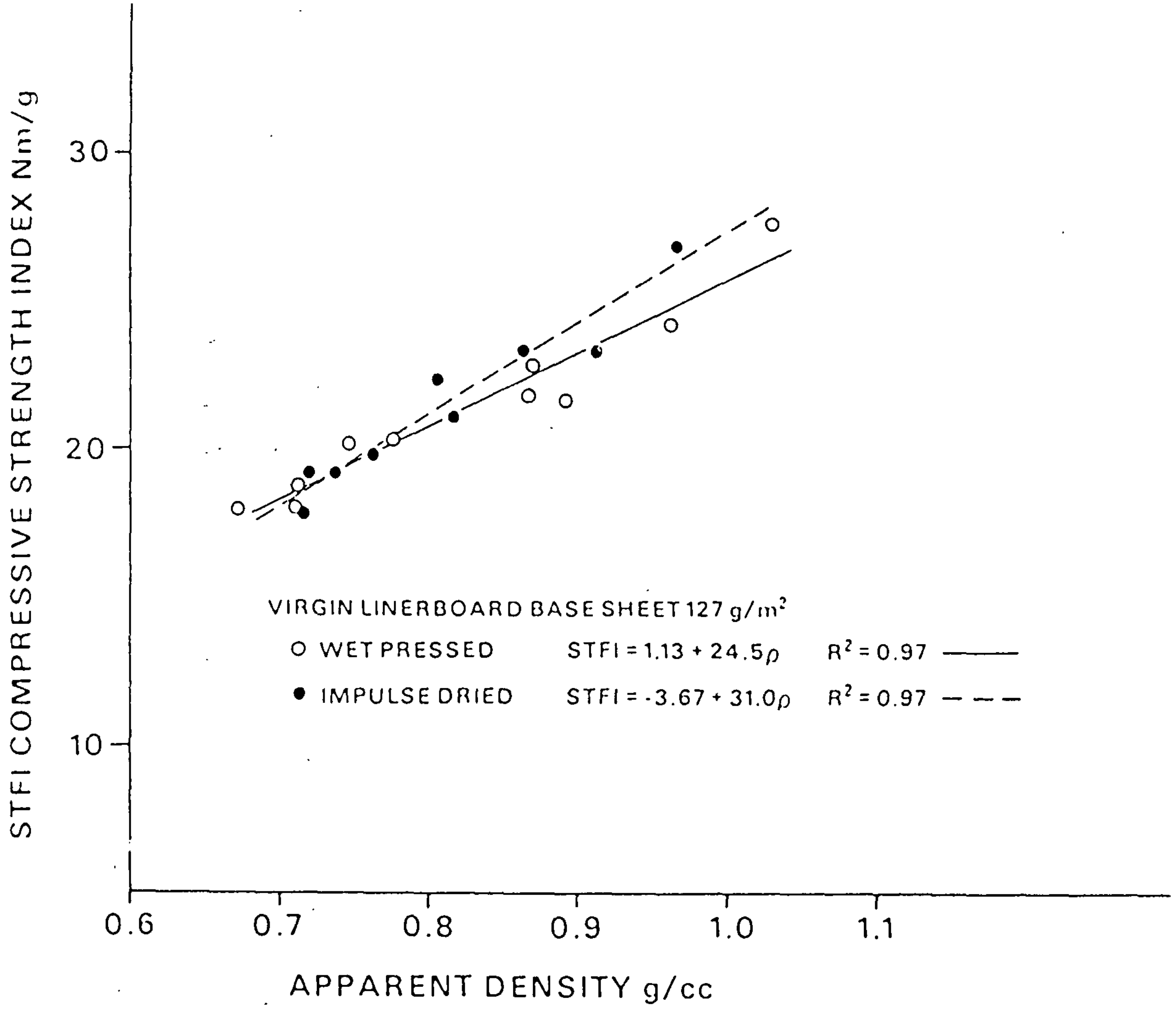

Figure 9. Strength-density relationships for densities produced by impulse drying and by wet pressing.

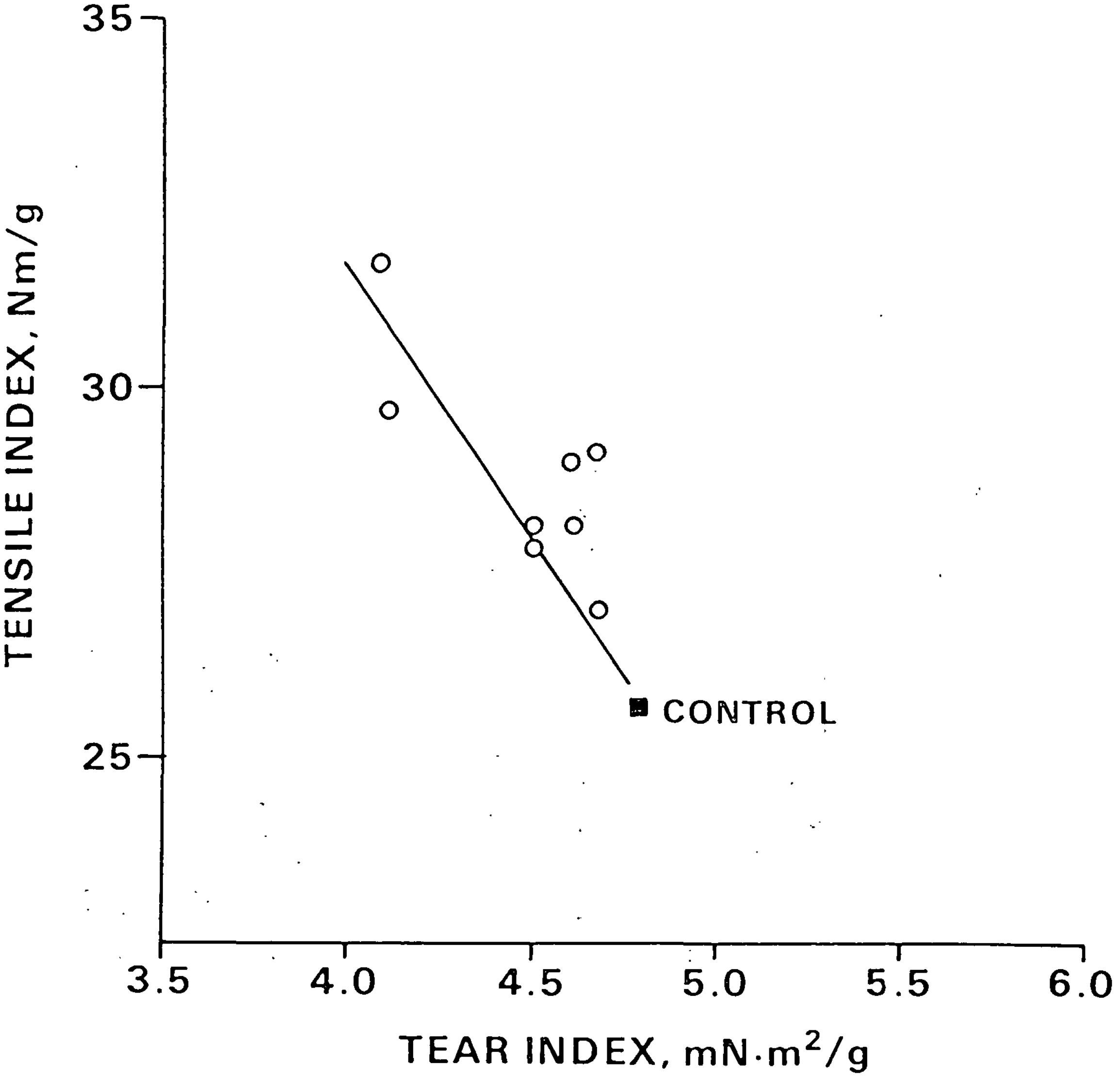

Figure 10. Tensile-tear relationship for newsprint.

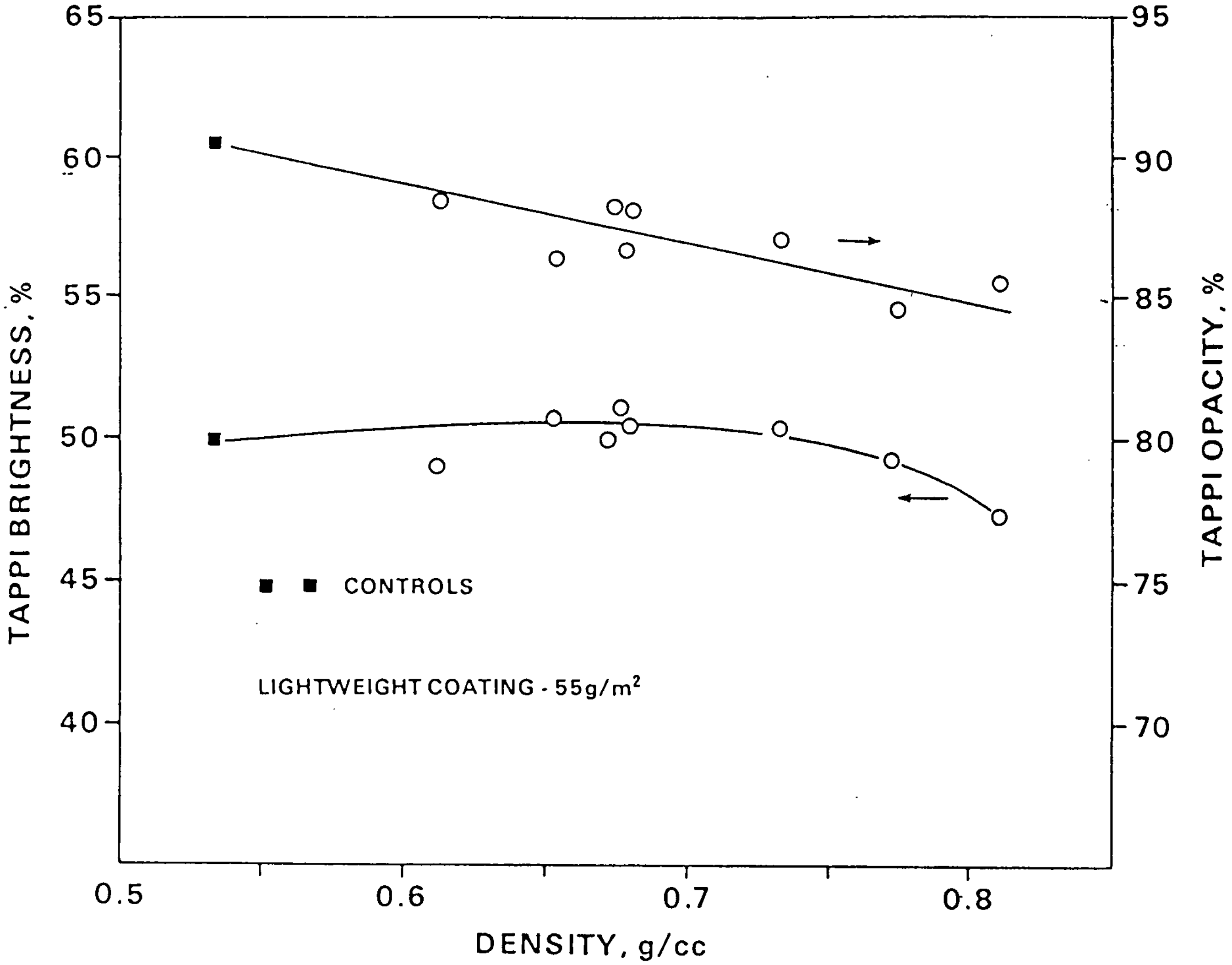

Figure 11. Brightness and opacity changes with density for lightweight coating paper.