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(54) Title: MICROWAVE PRE-TREATMENT OF LOGS FOR USE IN MAKING PAPER AND OTHER WOOD PRODUCTS



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A method of producing pulp for use in making paper products using microwave radiation to pretreat the source of pulp prior to further processing. Practising the method of the invention results in substantial energy savings while decreasing environmental impact and improving paper qualities.

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MICROWAVE PRETREATMENT OF LOGS FOR USE IN MAKING PAPER AND OTHER WOOD PRODUCTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial Number 60/347,818, filed November 9, 2001.

BACKGROUND OF THE INVENTION

[0002] In the manufacture of paper from wood, the wood is first reduced to an intermediate stage in which the wood fibers are separated from their natural environment and transformed into a viscous liquid suspension known as a pulp. There are several classes of techniques which are known, and in general commercial use, for the production of pulp from various types of wood. The simplest in concept of these techniques is the so-called refiner mechanical pulping (RMP) method, in which the input wood is simply ground or abraded in water through a mechanical milling operation until the fibers are of a defined or desired state of freeness from each other. Other pulping methodologies include thermo-mechanical pulping (TMP), chemical treatment with thermo-mechanical pulping (CTMP), chemi-mechanical pulping (CMP), and the so-called kraft or sulfate process for pulping wood. In all of these processes for creating pulps from wood, the concept is to separate the wood fibers to a desired level of freeness from the complex matrix in which they are embedded in the native wood.

[0003] Of the constituents of wood as it exists in its native state, cellulose polymers are the predominate molecule. Cellulose is desired for retention in the pulp for paper production. The second most abundant polymer in the native wood is lignin. Lignin, the least desirable component in the pulp, is a complex macromolecule of aromatic units with several different types of interunit linkages. In the native wood, lignin physically protects cellulose polysaccharides in complexes known as lignocellulosics that must be disrupted for there to be accessibility to the polysaccharides, (e.g., by enzymes) or to separate lignin from the matrix of the wood fibers.

[0004] Mechanical pulping accounts for about 25% of the wood pulp production in the world today. This volume is expected to increase in the future as raw materials become more difficult to obtain. Mechanical pulping, with its high yield, is viewed as a way to

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extend these resources. However, mechanical pulping is electrical energy-intensive and yields paper with lower strength than chemical pulps. Kraft pulp is often added to mechanical pulp to impart strength, but it is much more expensive than mechanical pulp. These disadvantages limit the use of mechanical pulp in many grades of paper.

[0005] In the industry, chemical pulps are preferred for a variety of paper grades, generally for better strength as a result of superior pulp quality (e.g., higher freeness, higher fiber length, and lower lignin content). However, chemical pulps are expensive to produce and fiber yields are generally very low (about 50%). On the other hand, mechanical pulps have fiber yields in excess of 90%, but pulp quality is degraded because fiberization is sometimes not complete and fibers can be severely damaged. Each process has its own inherent advantages and disadvantages, and papermakers must weigh these factors when developing a furnish for a particular paper grade. However, faced with the reality of more restrictive environmental regulations, increased energy costs, competitive pricing, and a more diverse raw wood resource, papermakers are being forced to be more creative in selecting furnish components. Therefore, efforts must be made to develop new technologies that improve the quality of mechanical pulps, making them more attractive as a component in higher quality paper grades.

[0006] In the RMP process, wood chips are refined atmospherically to make paper. This process requires approximately 100-135 Horse Power Days (HPD) (about 1800-2400 kWh) energy /ton of wood and produces pulp with lower strength.

[0007] In thermo-mechanical processes (e.g., TMP and CTMP), high temperatures are used to separate the fibers during refining. These processes generally require the refining to be carried out in one or more steps. The first step is usually a pressurized step with refining being performed at temperatures above 100°C and immediately below or at the softening temperature of lignin. During this step, the pulp is typically mechanically processed using the RMP method. In subsequent steps, the pressure and temperature is usually modulated to achieve the desired state of freeness between the fibers.

[0008] In the TMP process, a steam pressure of 30lb or less (gauge pressure) is applied to the chips for 2-5 minutes prior to refining. This pressure is critical to separate the cell wall fibers in such a way that the resulting paper has much longer fibers (increased tear index)

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than the straight RMP process. If one exceeds the pressure above 30 lbs during presteaming, then the lignin will be melted and deposited on the surface of fibers and the fiber flexibility will be lost resulting in poor quality fibers that resemble the fibers produced during medium density fiber board production. Therefore, it is critical to maintain the right gauge pressure during refining. The drawback of the TMP process is that it takes significantly higher amounts of energy compared to the RMP process. For example, the energy requirement during the TMP process is in the range of 140-220 HPD (about 2500-4000 kWh)/ton of wood. The steam pressure also results in the darkening of pulp. Thus, more bleach chemicals are needed to obtain paper of a desired brightness.

[0009] Relatively large total electric energy amounts or large quantities of input wood are required to produce pulps using the above mentioned pulping techniques. In particular, high energy inputs are generally required to obtain fiber separation in woods rich in lignin as such woods typically call for extended refining periods and high temperatures and/or pressures. Studies have also suggested that even thermal or chemical softening treatments of such woods does not guarantee a lower total energy consumption in the production of pulp. This is because unprocessed fibers that are only mildly separated by the thermal or chemical treatments are difficult to fibrillate during the refining mechanical process. Fibrillation is the separation of larger fibers into small, thread-like structures called fibrils. Fibrillation is necessary to increase the flexibility of the fibers and to bring about the fine material characteristics of quality processed pulp. It has been suggested that a decrease in energy consumption from an established level in various TMP and CTMP processes has been associated with the deterioration of certain pulp properties, including a reduction in the long fiber content of the pulp, a lower tear strength and tensile strength, and a higher shive content. As a result, high energy consumption in TMP and CTMP processes has been generally necessary in current pulping practices.

[0010] Biopulping techniques have been developed to supplement traditional pulping methods and have been shown to reduce energy requirements and improve paper properties. Biopulping is defined as the treatment of wood chips with a "natural" wood decay fungus prior to mechanical pulping. In this technology, wood chips are steamed, cooled, inoculated with a fungus, and incubated for two weeks under forced aeration to remove metabolic heat generated by the fungus. The process saves a substantial amount

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of electrical energy (about 30%), improves paper quality, reduces the environmental impact of pulping, and enhances economic competitiveness. However, the economics of the process is highly dependent on the treatment time and processing costs such as those associated with ventilation of the pile for two weeks to remove metabolic heat generated by the fungus.

[0011] The direct application of enzymes has been proposed as a means to reduce costs associated with energy expenditures and processing required in traditional pulping methodologies. For example, lignin-degrading fungi such as *Ceriporiopsis subvermispora*, *Hyphodontia setulos*, *Phlebia subserialis*, *Phlebia brevispora*, *Phlebia tremellosa* and *Phanerochaete chrysosporium*. used in biopulping techniques secrete enzymes inside the wood cell walls which are responsible for breakdown or modification of lignin. However, it is known that direct application of isolated enzymes on wood chips does not yield results similar to those obtained with fungal pretreatment because these enzymes cannot penetrate the wood due to their larger size compared to the pore size in the wood. Live fungus is required to penetrate the wood and transport enzymes inside the wood cell walls. Because of the low accessibility of wood chips for enzymatic modification, incorporation of an enzymatic treatment step into a mechanical pulping process can be expected to be successful only after the primary stage of refining, during subsequent process steps. In pilot-scale experiments, an energy savings of 10-15% with CBH I (modified cellulase) has been reported with some improvement in tensile index, a strength property. However, technical difficulties have been reported in applying enzymes after primary stage refining because pulp after primary stage refining enters into secondary stage refining within seconds. Based on this difficulty, efforts directed to enzyme treatment are now mainly on reject pulp samples. Because most of the energy during TMP refining is consumed during primary and secondary stage refining and not during reject refining, direct enzyme application is useful only as a downstream process. Thus, to date, energy savings due to enzymes have been insignificant.

[0012] Similarly, in certain markets, lumbers are treated with chemicals to protect them from the environment and provide stability to the product. Currently, it is not possible for high molecular weight compounds to penetrate the logs or the lumber for certain applications, such as wood hardening. A technique that enhances permeability of wood to

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larger molecules would therefore be widely applicable, even outside the pulp and paper industry.

[0013] Another promising technology used in the pulp and paper industry for improving paper brightness, opacity, and bonding strength, as well as reducing energy consumption during drying, is a technique termed "fiber loading." In fiber loading, calcium carbonate is deposited as a filler within, on the surface of, and outside the fibers. The process consists of at least two steps. First, calcium hydroxide is mixed into a pulp fiber slurry. Next, the pulp and calcium hydroxide mixture is reacted using a high consistency pressurized reactor (refiner or disk disperser) under carbon dioxide pressure to precipitate calcium carbonate. Calcium carbonate formed is termed fiber-loaded precipitated calcium carbonate (FLPCC). However, most applications of fiber loading have focused on fiber loading chemical pulps.

[0014] In addition to the above-described efforts to increase pulp yield, decrease energy consumption and enhance paper quality, another issue concerning the pulp and paper industry is pitch content. Pitch is a mixture of hydrophobic resinous materials and constitutes about 2-8% of the total wood weight depending upon the species and the time of the year. It causes a number of problems in wood processing, including at least deposits on tile and metal surfaces, plugging of drains, discoloration of felt, tears and other defects in paper and downtime for cleaning. Traditional methods of controlling pitch include natural seasoning of wood before pulping and/or adsorption and dispersion of the pitch particles with chemicals. During the pulping and papermaking processes, pitch reduction methods can also include adding fine talc, dispersants and other kinds of chemicals.

[0015] Biotechnological and enzymatic methods have also been developed and used industrially to reduce pitch. It has been reported that lipases reduce pitch by hydrolyzing triglycerides to glycerol and free fatty acids in mechanical pulps. A commercial lipase enzyme product, RESINASE™, has been developed (Novo Nordisk Biochem of North America, Franklinton, NC) to reduce pitch deposits from groundwood pine pulp. Another commercial product, CARTAPIP™ (Agra Sol Inc., Raleigh, North Carolina, U.S.A.) is a fungal inoculum of the ascomycete *Ophiostoma piliferum*. A water slurry of the fungal

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spores is sprayed onto wood chips as they are piled prior to pulping. The fungus invades the wood cells, degrading the pitch.

[0016] However, both traditional and biotechnological methods of pitch control fail to remove all traces of pitch from most wood species and thus only alleviate, but do not eliminate the problems associated with pitch in wood processing. A method that would provide enhanced pitch reduction would therefore be desirable.

[0017] Yet another dilemma faced by the pulp and paper industry is blue staining of wood. This problem occurs when freshly cut logs are stored for a long period of time in wood yards prior to debarking and chipping. These logs are normally colonized by the blue stain fungi present in the wood yard. The colonization results in wood staining and consequently, pulps with lower brightness. More bleach chemicals are therefore needed to overcome the loss of brightness which, in turn, results in increased costs for effluent treatment. This is a serious problem in the southern parts of the U.S. where the logs are exposed to high temperature and humidity, which tend to exacerbate the problem. Biotechnological methods of reducing blue staining include the use of CARTAPIPTM (Agra Sol Inc., Raleigh, North Carolina, U.S.A.), which, as discussed, is also used in reducing pitch. It has been shown that treatment with CARTAPIPTM also controls unwanted colored blue stain microorganisms that lead to increased costs in the purchase of bleach chemicals. However, as with pitch reduction methods, efforts to reduce blue staining have not been completely successful.

[0018] What is needed is an alternative method for producing pulp in an energy efficient manner that also improves paper strength properties while decreasing pollution. Also desirable is a method that enhances permeability and porosity of the internal structure of wood, thereby providing increased access for fungi, enzymes and other large molecules and chemicals.

SUMMARY OF THE INVENTION

[0019] Described is a method of pulping wood, including the step of treating, pretreating or exposing a source of pulp to microwave radiation to reduce substantially the power requirements, chemical requirements, or process time to convert the source of pulp to pulp.

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[0020] Also described is a method of producing pulp for use in making paper products. In a preferred practice, the method includes steps of treating wood logs with or exposing logs to microwave radiation, chipping the logs and pulping the wood chips with a mechanical pulping process. Suitable mechanical pulping processes include RMP, TMP and CTMP. Optionally, the method can include fiber loading the pulp.

[0021] Chips obtained from microwaved logs could also be treated with microorganisms and enzymes to save energy, improve paper strength, reduce pitch content, and increase chemical penetration to benefit the pulp and paper and lumber processing industries.

[0022] The method can be used with hard- or softwood species as pulp sources. Suitable hardwood species include aspen, eucalyptus and oak. Suitable softwood species include spruce and pine.

[0023] The invention also encompasses a paper produced according to the methods described. Suitably, the paper demonstrates improved strength characteristics over methods not including a microwave step. Most suitably, the paper demonstrates at least a 10% increase in measurements of tensile index, tear and burst.

[0024] Another facet of the invention is a method of producing wood pulp that includes steps of treating the wood source, e.g., logs, with microwave radiation, chipping the logs to provide wood chips, inoculating the wood chips with a fungus and mechanically processing the inoculated wood chips to provide pulp. Suitable fungal species include the "white rot" species commonly used in biopulping. Included among the suitable species are *Ceriporiopsis subvermispora*, *Hyphodontia setulos*, *Phlebia subserialis*, *Phlebia brevispora*, *Phlebia tremellosa* or *Phanerochaete chrysosporium*. An additional species which can be used in a method of the invention is a white or colorless species of *Ophistoma piliferum*, which can be used to reduce pitch and/or blue staining.

[0025] The invention is also directed to a method of producing pulp that includes the steps of microwaving wood, chipping the wood, applying enzymes to the wood chips and mechanically processing the enzyme-treated wood chips to provide pulp. Suitable enzymes include lignin-degrading enzymes, xylanases, pectinases, lipases and cellulases.

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[0026] The invention provides for energy savings during wood pulping and includes a method of reducing energy input requirements. The method includes steps of treating wood with microwave radiation, chipping the wood and mechanically pulping the wood chips, wherein the energy input requirement is reduced at least about 8% over a method not including the step of treating logs with microwave radiation. Suitably, the energy requirement is reduced at least about 8% to about 15%.

[0027] A method of reducing pitch is described wherein a pulp source is treated with microwave radiation prior to subsequent process steps.

BRIEF DESCRIPTION OF THE FIGURES

[0028] FIG. 1 is a photograph of a waveguide and chamber for a 60-kW industrial microwave oven that can be used in the methods of the invention.

[0029] FIG. 2 is a graph showing radial temperature as a function of microwave power level for 20- and 50-kW treated logs.

[0030] FIG. 3 is a photograph showing steam jet issuing from end of a log after microwave treatment at 50 kW for 5 minutes.

[0031] FIG. 4 is a photograph showing extensive radial checking after microwave treatment at 50 kW for 5 minutes.

[0032] FIG. 5 is a scanning electron micrograph of a tangential fracture surface after microwave treatment at 50 kW for 5 minutes.

[0033] FIG. 6 is a scanning electron micrograph of a tangential fracture surface after microwave treatment at 50 kW for 5 minutes.

[0034] FIG. 7 is a graph showing freeness as function of refiner energy consumption for several microwave pretreatments.

[0035] FIG. 8 is a graph showing refiner energy savings as a function of microwave power level for several microwave pretreatments.

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[0036] FIG. 9 is a graph showing tensile index as a function of microwave power level for microwave-pretreated black spruce TMP.

[0037] FIG. 10 is a graph showing estimated annual pulp cost savings for 800 ton/day for a mill based on substitution of microwave-pretreated TMP for kraft pulp.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0038] It has now been discovered that a pulping process that includes a pre-treatment or exposure of the pulp source to microwave radiation allows for increased porosity and permeability of the pulp source. Generally speaking, this improved pulping process is most applicable to wood, generally in the form of logs. The increase in permeability after microwaving pretreatment is due, in part, to breakage of pit membranes and vessel cell ends caused by steam pressure generated inside the wood. Breakage of pit membranes and vessel cell walls by microwave exposure substantially increases access of process chemicals to wood. During the microwaving process, some of the water in the wood is converted to steam. Major advantages of microwave over other conventional methods are increased pulp yield, high speed, low or no chemical use, low wood inventories, low waste production, and low process cost during papermaking.

[0039] Not to be bound by theory, it is believed that the microwave process leads to steam pressure build-up inside the logs. This separates cell walls, increasing porosity and permeability so that less energy is required during subsequent refining and also results in a stronger paper product.

[0040] As used herein, "mechanical processing" and "mechanically processing" refer to processing methods in which mechanical, electrical or thermal energy is used to break down intact wood into constituent fibers to produce wood pulp with a desired level of freeness. Suitable methods include TMP, RMP and CTMP. TMP is a preferred method.

[0041] As used herein, "biopulping" refers to a method used in the production of pulp that includes the use of a biological system to perform, or to assist in performing, the pulping of wood. Preferably, biopulping is carried out by inoculating steamed wood chips with a species of fungi known to degrade or modify lignin. Preferred fungal species include the so-called "white rot" fungi. Preferred among the white rot species are species of

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Ceriporiopsis subvermispora, *Hyphodontia setulos*, *Phlebia subserialis*, *Phlebia brevispora*, *Phlebia tremellosa* or *Phanerochaete chrysosporium*.

[0042] As used herein, the terms “reduced energy input requirements,” “improved strength properties,” and “enhanced permeability” are relative terms that indicate a reduction, improvement or enhancement, respectively, over a pulping method that does not include a microwave treatment (including modifications of a method to accommodate a microwave step), but otherwise including the same steps as the described methods. Suitably, the method of the invention reduces the energy input requirement at least about 8%. Most suitably, the method of the invention reduces the energy input requirement at least about 8% to about 15%. Paper produced according to the method of the invention suitably demonstrates at least about a 10% increase in strength properties. The permeability of wood to chemicals also is enhanced by exposure of the wood to microwave radiation according to one aspect of a method of this invention.

[0043] The benefits of microwave pre-treatment can be realized in many aspects of paper manufacturing. Microwave pretreatment of wood can reduce electrical power requirements, improve paper quality, reduce pitch and reject contents, improve paper machine operation and save energy during drying of pulp, etc. The technology also has potential for improving existing biopulping processes, by preventing blue staining of wood, enhancing the penetration of enzymes and other large molecules into wood, improving fiber loading processes, and improving chemical penetration during lumber processing.

[0044] In a method of the invention, the steps of treating logs with microwave radiation, chipping the logs and pulping the wood chips with a mechanical pulping process are carried out.

[0045] Microdry, Inc. (Crestwood, KY) is a manufacturer of custom industrial microwave ovens suitable for use in the present invention. Individual logs can be manually placed in the microwave chamber until appropriate treatment time and frequency is determined. Treatment parameters are dependent upon a number of factors, including type of wood, diameter of the log and moisture content. After optimization of treatment parameters,

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however, a continuous belt transport system capable of accommodating logs can be used. Microwaving can be done prior to or after debarking.

[0046] Chipping of logs is within those of skill in the art and can be accomplished with any known suitable techniques. One suitable technique is to use a Sprout-Waldron Model D2202 single rotating 300 mm diameter disk refiner. After chipping, a mechanical pulping process is carried out. Mechanical pulping processes include RMP, TMP and CTMP. In thermomechanical pulping, high power refiners are used to mechanically reduce wood chips to fiber. To aid in this process, elevated temperatures are used to soften the wood. Several refining "passes" are generally required to obtain a target freeness. The first pass is usually defibration at temperatures above 100°C and immediately below or at the glass transition temperature of lignin ($T_g < 124^\circ\text{C}$). During this pass, chips are typically fiberized under pressure using an aggressive plate pattern to produce a high freeness pulp. This pulp is then further reduced in multiple passes through an atmospheric refiner until the desired pulp freeness is obtained. The inventors have surprisingly found that microwave treatments alter the structure of wood such that fiberization occurs more easily during mechanical pulping, thereby reducing refiner energy requirements and improving the pulp.

[0047] Optionally, the method can include fiber loading the pulp. Fiber loading is described in U.S. Patent Number 5,223,090, issued June 29, 1993, and is incorporated herein by reference.

[0048] Further methods of the invention include producing pulp by treating logs with microwave radiation, chipping the logs to provide wood chips, inoculating the wood chips with a fungus and mechanically processing the inoculated wood chips. Microwave treatment, chipping and mechanical processing is carried out as described above. Included among the suitable species for inoculation of the wood chips are *Ceriporiopsis subvermispora*, *Hyphodontia setulos*, *Phlebia subserialis*, *Phlebia brevispora*, *Phlebia tremellosa* or *Phanerochaete chrysosporium*. When microwaved logs are debarked, chipped and inoculated with biopulping fungus, the treatment time is substantially reduced as compared to conventional biopulping without the use of microwave pretreatment. As discussed, it is believed that the enhanced porosity of the microwaved chips provides faster colonization of these chips by the fungus. Further, microwaved logs or chips from

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these logs can be inoculated with CARTAPIP™ or other fungal species to remove blue stain microorganisms or pitch. As described above, the enhanced porosity facilitates colonization, thereby reducing treatment and incubation times.

[0049] A method of the invention for reducing pitch and/or blue staining can be carried out using a colorless species of *Ophistoma piliferum*, which can be used to reduce pitch and/or blue staining. One species of *Ophistoma piliferum* is sold under the trade mark CARTAPIP™ by Agra Sol Inc. of Raleigh, North Carolina, U.S.A.. In the method of the invention, this fungus is suitably applied to wood chips subsequent to microwaving as described. U.S. Patent No. 5,607,855, issued March 4, 1997, describes a suitable method of reducing pitch with fungi and is incorporated herein by reference. Even without the use of CARTAPIP™, microwaving of logs can be used to reduce or remove resinous material. Not to be bound by theory, it is believed that some of the components of this resinous material that are sticky, such as triglycerides, are converted into a less sticky material after microwaving.

[0050] The invention is also directed to a method of producing pulp that includes the steps of microwaving wood, chipping the wood and applying enzymes to the wood chips. Suitable enzymes include lignin-degrading enzymes, xylanases, pectinases, lipases and cellulases.

[0051] The invention provides for energy savings during wood pulping and includes a method of reducing energy input requirements. The method includes steps of treating wood with microwave radiation, chipping the wood and mechanically pulping the wood chips, wherein the energy input requirement is reduced at least about 8% over a method not including the step of treating logs with microwave radiation. Suitably, the energy requirement is reduced at least about 8% to about 15%. The inventors have discovered that higher energy savings correlate with higher power levels used during the microwave pretreatment step. Energy savings are also observed during debarking and chipping compared to logs that were not microwaved.

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[0052] EXAMPLES

[0053] Details of the invention will become more apparent by reference to the following non-limiting examples, which, in some cases, illustrate laboratory-scale embodiments and results achieved thereby.

Example 1: Microwaving Logs and Structural Effects

[0054] Microdry, Inc. (Crestwood, KY) is a manufacturer of custom industrial microwave ovens suitable for use in the present invention. A high capacity microwave oven was used for initial tests (FIG. 1). This oven is connected to a variable-power (up to 60 kW) 915-MHz frequency generator. Individual logs can be manually placed in the microwave chamber until appropriate treatment time and frequency is determined. Treatment parameters are dependent upon a number of factors, including type of wood, diameter of the log and moisture content. After optimization of treatment parameters, however, a continuous belt transport system capable of accommodating logs can be used.

[0055] Microwaved logs or chips obtained from these logs demonstrate increased porosity as has been observed in treated logs. In general, as shown in FIG. 2, it has been determined that higher power levels result in higher log temperatures, with steeper temperature gradients from bark to pith. Of particular interest are results obtained using spruce logs microwaved for 5 min at 50 kW. Within a couple of minutes, splitting became intense and steam jets shot out the ends of the logs (FIG. 3). In just 5 minutes, the logs had lost about 25% of their weight or nearly all of their moisture. A visual examination of the ends of the logs revealed extensive radial checking (FIG. 4). Several fracture surfaces from logs treated at 5 min/50 kW were sampled to identify possible morphological changes in the fiber structure. A scanning electron microscope was used to obtain images of both tangential and radial surfaces (FIGS. 5 and 6).

[0056] Based on the results of exploratory mechanical pulping trials, it was evident that microwave pretreatment can substantially lower refiner energy requirements while improving pulp quality. To verify this, a more extensive evaluation was undertaken using the logs that were microwave pretreated at several different power levels. The logs were debarked and chipped, then refined by the established TMP protocol. FIG. 7 shows pulp freeness as a function of total refining energy for the last three atmospheric refining

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passes, indicating total energy savings for all microwave pretreatments. Of particular interest is the relationship of increased energy savings to increased microwave power levels, as can be seen in FIG. 8. Handsheets made from these pulps also exhibited an increase in mechanical properties, with only moderate reductions in brightness. As with total energy reduction, an increase in mechanical properties seems to correlate with an increase in microwave power level, as can be seen in FIG. 9. Because pulp quality is improved, kraft components can be reduced, with a resultant savings in total pulp cost, as demonstrated in FIG. 10. An estimate of capital costs for 20-kW and 50-kW systems could range from \$7.5 to \$12.5 million.

Example 2: Microwave Pretreatment of Spruce Logs

[0057] Spruce logs were divided into two lots. One lot was frozen and used as a control. The other lot was treated for 5 minutes with a high power microwave generator (50kW at 915 MHz). During microwaving, significant moisture loss was observed and a temperature of 130°C inside the log was recorded. Prior to refining atmospherically, both the control and the microwaved logs were completely submerged in water overnight to maintain the same moisture content in both the logs. Logs were then debarked, chipped, and refined through the RMP process. Following results were obtained (Table 1):

Table 1. Energy requirements and paper strength properties during RMP process

Parameters	Control	Treatment (Microwaved)
Energy during refining (Wh/kg)	2411	2051
Burst index (kN/g)	0.98	1.33
Tear index (mNm ² /g)	3.31	3.91
Tensile index (Nm/g)	23.6	28.6
Breaking length (m)	2408	2912

[0058] The data in Table 1 indicates that the microwave treatment improved all major strength properties significantly with reduced energy input requirements. The observed enhancement of strength properties was surprising because microwaving resulted in a drying of logs which is typically associated with a decrease in paper strength properties.

[0059] Other highly unexpected results were obtained during bleaching. Although the initial pulp brightness of the treated samples was approximately 4 points lower than the

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control, as reported in Table 2, the microwave-treated samples demonstrated increased susceptibility to bleaching chemicals. As can be seen from the data, control samples required 2% hydrogen peroxide to reach the target brightness of 73% ISO, whereas treated samples required only 1.5% hydrogen peroxide to reach to the same level of brightness.

[0060] Thus, an additional advantage of the invention is a reduction in amounts of bleaching chemicals required during bleaching. This, in turn, increases the opacity of the resulting paper and reduces the effluent treatment costs associated with paper production.

Table 2. Brightness response

Treatments	Brightness (%ISO)
Control ¹	
Initial Brightness	59.6
1.5% Hydrogen Peroxide + 1.5% Sodium Hydroxide	71.4
2% Hydrogen Peroxide + 2% Sodium Hydroxide	73.6
[0061] Treatment ²	
Initial Brightness	55.5
1.5% Hydrogen Peroxide + 1.5% Sodium Hydroxide	73.4

¹ Control produced using the conventional TMP process. Fifty five percent of this pulp was mixed with 45% of the Ground Wood Pulp (GWP^a). The initial brightness of this mixed pulp before bleaching was 59.6% ISO. Fifty percent of this mixture was bleached with 1.5% and 2% of hydrogen peroxide.

² Treatment produced from microwaved logs using the conventional RMP process. Fifty five percent of this pulp was mixed with 45% of GWP. The initial brightness of this mixed pulp before bleaching was 55.5% ISO. Fifty percent of this mixture was bleached with only 1.5% hydrogen peroxide.

^aGWP was obtained from a mill producing lightweight coated (magazine) paper.

Example 3: Microwave Pretreatment of Pine Logs

[0062] Objective: To achieve electrical energy savings and improvements in paper strength by microwaving pine logs prior to mechanical pulping.

[0063] Materials: Pine logs were received from a mill specializing in the production of light weight coated paper. Logs were microwaved at Microdry in Louisville, KY. Logs were debarked and chipped to a nominal size of 6-14 mm. Chips were placed in plastic freezer bags and frozen to prevent the growth of contaminating microorganisms. Log discs were cut before debarking and chipping that was approximately 3 centimeters thick.

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Moisture content varies from approximately 50%-56% depending on the microwave treatment time.

[0064] Microwave Treatments: Logs were subject to three microwaving conditions. Logs were microwaved at 50 kW for 5 minutes (50/5), 20 kW for 6 minutes (20/6), and 20 kW for 8 minutes (20/8).

[0065] Chip fiberization, pulp refining and handsheet production: Microwaved wood chips were fiberized in a Sprout-Waldron Model D2202 single rotating 300 mm diameter disk refiner. Energy consumption was measured using an Ohio Semitronic Model WH 30-11195 integrating Wattmeter attached to the power supply side of the 44.8 kW electric motor. Feed rate through the refiner was between 10 kW and 15 kW. Energy reported in WH/kg. Refiner plate settings were 0.025 inch, 0.014 inch, 0.010 inch, and 0.008 inch. Pulp was collected at each pass as hot water slurry. Between the passes the pulp slurry was dewatered to approximately 25% solids in a porous bag by vacuum. Dilution water at 85 degrees Celsius was then added each time as the pulp was fed into the refiner. Samples of the pulp were taken and tested for the Canadian Standard Freeness (CSF). Samples refined to 100 CSF. Handsheets were prepared and tested using TAPPI standard testing methods.

[0066] Results: See Table 3.

Table 3: Pine Treatments

Sample Identification Including Log Size	Burst (kN/g)	Tear (mN-m ² /g)	Energy Savings (%)
Control	0.47	1.99	-----
50/5	0.56	2.43	11.7
20/6	0.53	2.20	6.9
20/8	0.52	2.14	9.1

Example 4: Microwave Pretreatment of Aspen Logs

[0067] Objective: To achieve electrical energy savings and improvements in paper strength by microwaving aspen logs prior to mechanical pulping.

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[0068] Materials: Aspen logs were received from a mill specializing in the production of light weight coated paper. Logs were microwaved at Microdry in Louisville, KY. Logs were debarked and chipped at FPL to a nominal size of 6-14 mm. Chips were placed in plastic freezer bags and frozen to prevent the growth of contaminating microorganisms. Log discs were cut before debarking and chipping that was approximately 3 centimeters thick. Moisture content varies from approximately 50%-56% depending on the microwave treatment time.

[0069] Microwave Treatments: Logs were subject to three microwaving conditions. Logs were microwaved at 50 kW for 5 minutes (50/5), 20 kW for 6 minutes (20/6), and 20 kW for 8 minutes (20/8).

[0070] Chip fiberization, pulp refining and handsheet production: Microwaved wood chips were fiberized in a Sprout-Waldron Model D2202 single rotating 300 mm diameter disk refiner. Energy consumption was measured using an Ohio Semitronic Model WH 30-11195 integrating Wattmeter attached to the power supply side of the 44.8 kW electric motor. Feed rate through the refiner was between 10 kW and 15 kW. Energy reported in WH/kg. Refiner plate settings were 0.025 inch, 0.014 inch, 0.010 inch, and 0.008 inch. Pulp was collected at each pass as hot water slurry. Between the passes the pulp slurry was dewatered to approximately 25% solids in a porous bag by vacuum. Dilution water at 85 degrees Celsius was then added each time as the pulp was fed into the refiner. Samples of the pulp were taken and tested for the Canadian Standard Freeness (CSF). Samples refined to 100 CSF. Handsheets were prepared and tested using TAPPI standard testing methods. Table 4 describes the results.

Table 4: Aspen Treatments

Sample Identification Including Log Size	Burst (kN/g)	Tear (mN-m ² /g)	Energy Savings (%)
Control	0.46	1.85	-----
50/5	0.47	1.85	3.4
20/6	0.49	1.86	1.9
20/8	0.50	1.98	1.8

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Example 5: Pitch reduction

[0071] Logs were microwaved as described in Example 1. The control consisted of logs that did not undergo microwave treatment. All logs were then chipped and the chips were extracted with dichloromethane (DCM). A significant decrease in pitch was observed in the microwave pre-treated samples. Results are shown in Table 5.

Table 5: Dichloromethane extraction

Pitch/Resin Acids	Control	Treated Microwaved 20 kw/6 min	Treated Microwaved 50 kw/5 min
DCM Extractives (% dry weight basis)	1.81	1.70	1.55
% reduction over control	-	6	14
Resin Acids		b	
Pimaric acid	98.5	77.1	83.0
Sandaracopimaric acid	134	95.9	93.0
Isopimaric acid	359	278	341
Levopimaric acid	246	145	258
Dehydroabietic acid	1310	839	892
Abietic acid	147	151	191
Neoabietic acid	< 25	< 25	< 25
Chlorodehydroabietic acid	< 25	< 25	< 25
Dichlorodehydroabietic acid	< 25	< 25	< 25
Total identified resin acids (µg/dry weight basis)	2290	1590	1860
% reduction over control	-	31	19

Example 6: Enzyme Application

[0072] Logs are microwaved as described in Example 1. Logs are then chipped and sprayed with compositions containing a mixture of lipases, xylanases, pectinases,

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cellulases and lignin-degrading enzymes. Upon mechanical processing to provide pulp, a decrease in energy input requirements and an increase in paper strength and desirable optical characteristics are noted.

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WE CLAIM:

1. (Canceled)
2. A method of producing pulp for use in making paper products, wherein the pulp source comprises wood logs, further comprising the steps of:
treating the wood logs with microwave radiation;
chipping the logs to provide wood chips; and
mechanically processing the wood chips to provide pulp.
3. The method of claim 2 further comprising the step of fiber loading the mechanically processed pulp.
4. The method of claim 2, wherein the logs comprise a hardwood species.
5. The method of claim 4 wherein the logs comprise at least one of an aspen species, a eucalyptus species and an oak species.
6. The method of claim 2, wherein the logs comprise a softwood species.
7. The method of claim 6, wherein the logs comprise at least one of a spruce species and a pine species.
8. The method of claim 2, wherein mechanically processing comprises an RMP process, a TMP process or a CTMP process.
9. The method of claim 2, wherein mechanically processing comprises a TMP process.
10. A paper produced according to the method of claim 2.
11. The paper of claim 10, wherein the paper demonstrates improved strength properties over a paper produced according to a method not including treating logs with microwave radiation.

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12. The paper of claim 10 wherein the paper demonstrates at least about a 10% increase in measurements of tear index, burst index and tensile index.
13. A method of producing pulp for use in making paper products, the method comprising the steps of:
 - treating wood logs with microwave radiation;
 - chipping the logs to provide wood chips;
 - inoculating the wood chips with a fungus; and
 - mechanically processing the inoculated wood chips to provide pulp.
14. The method of claim 13, wherein the fungus comprises a white rot fungus.
15. The method of claim 14, wherein the fungus comprises *Ceriporiopsis subvermispora*, *Hyphodontia setulos*, *Phlebia subserialis*, *Phlebia brevispora*, *Phlebia tremellosa* or *Phanerochaete chrysosporium*.
16. The method of claim 13, wherein the fungus comprises a white or colorless species of *Ophistoma piliferum*.
17. A method of producing pulp for use in making paper products, the method comprising the steps of:
 - treating wood logs with microwave radiation;
 - chipping the logs to provide wood chips;
 - treating the wood chips with enzymes; and
 - mechanically processing the enzyme-treated wood chips to provide pulp.
18. The method of claim 17 wherein the enzymes comprise at least one of lignin-degrading enzymes, xylanases, pectinases, lipases and cellulases.
19. A method of reducing energy input requirements during wood pulping comprising the steps of:
 - treating logs with microwave radiation;
 - chipping the logs to provide wood chips; and
 - mechanically pulping the wood chips to provide pulp;

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wherein the energy input requirement is reduced at least about 8% over a method not including the step of treating logs with microwave radiation.

20. The method of claim 19 wherein the energy input requirement is reduced at least about 8% to about 15% over a method not including the step of treating logs with microwave radiation.
21. The method of claim 2 wherein treating wood logs with microwave radiation comprises microwaving the logs with a 915 MHz microwave generator for 5 minutes at 50 kW.
22. The method of claim 21 wherein treating the logs with microwave radiation results in a temperature of 130°C inside the logs.
23. The method of claim 12, wherein the burst index is increased at least about 30%, the tear index is increased at least about 15% and the tensile index is increased at least about 20%.
24. A method of reducing pitch in a wood log comprising the step of treating a wood log with microwave radiation.
25. The method of claim 24 wherein the wood log comprises a softwood species.
26. The method of claim 24 wherein the wood log comprises a hardwood species.

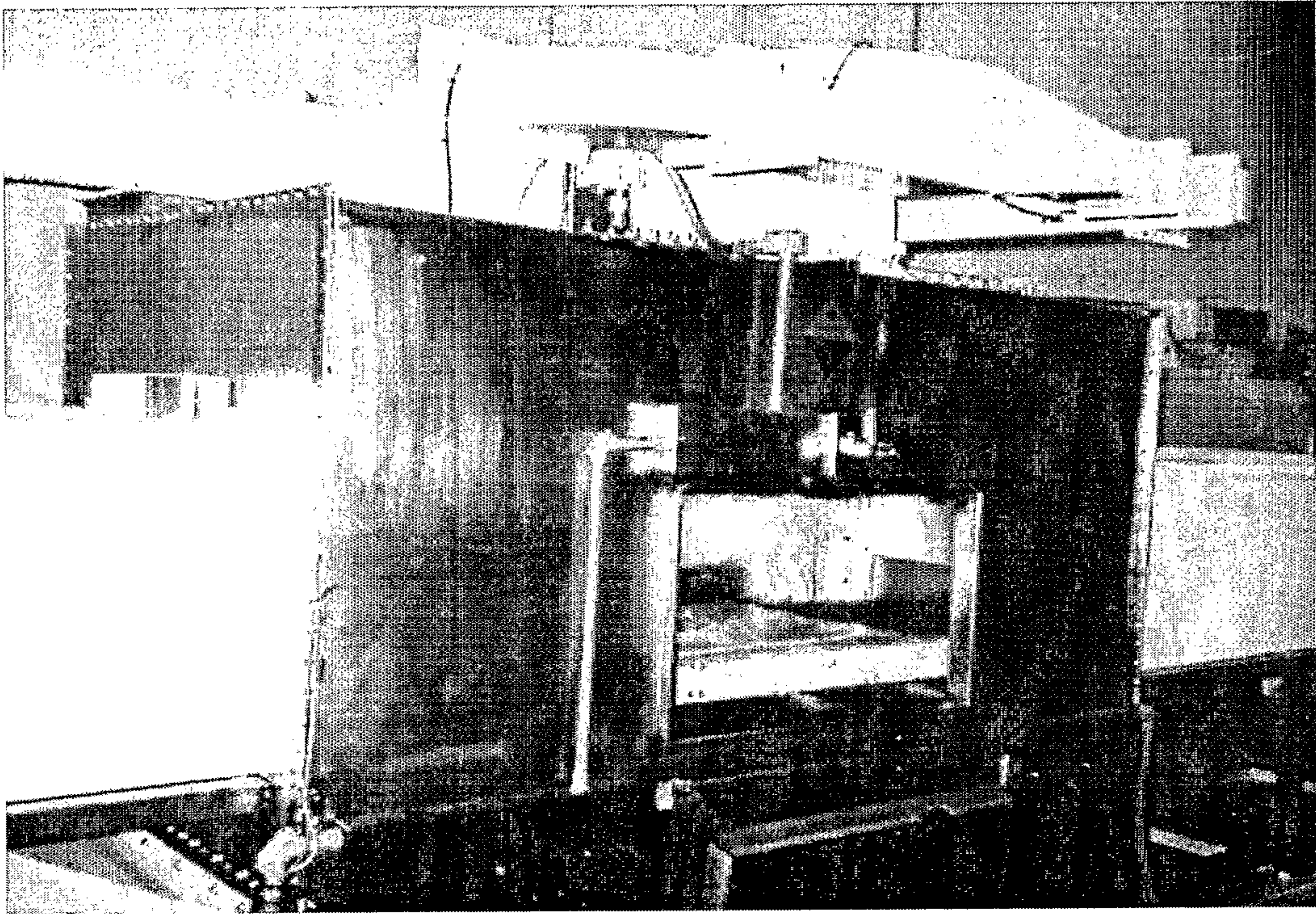
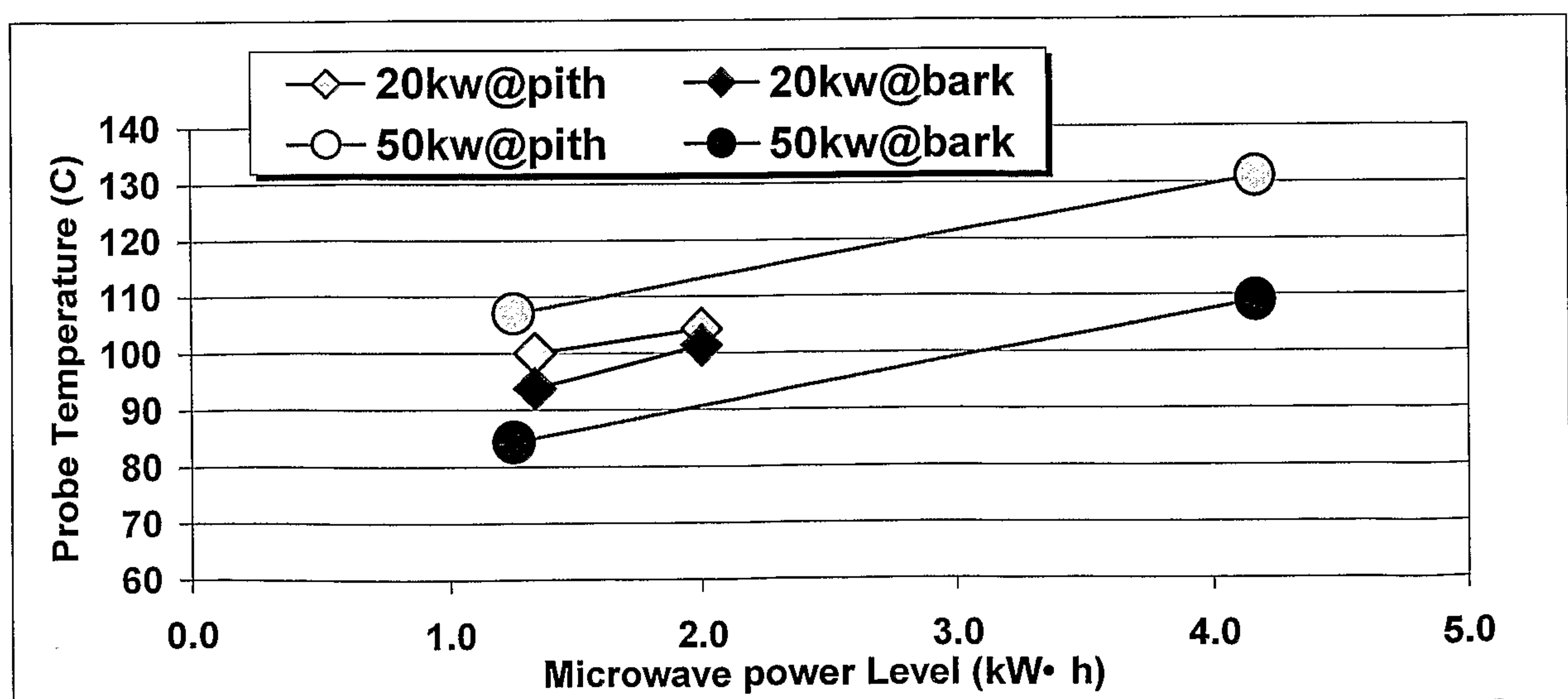
**FIG. 1****FIG. 2**



FIG. 3

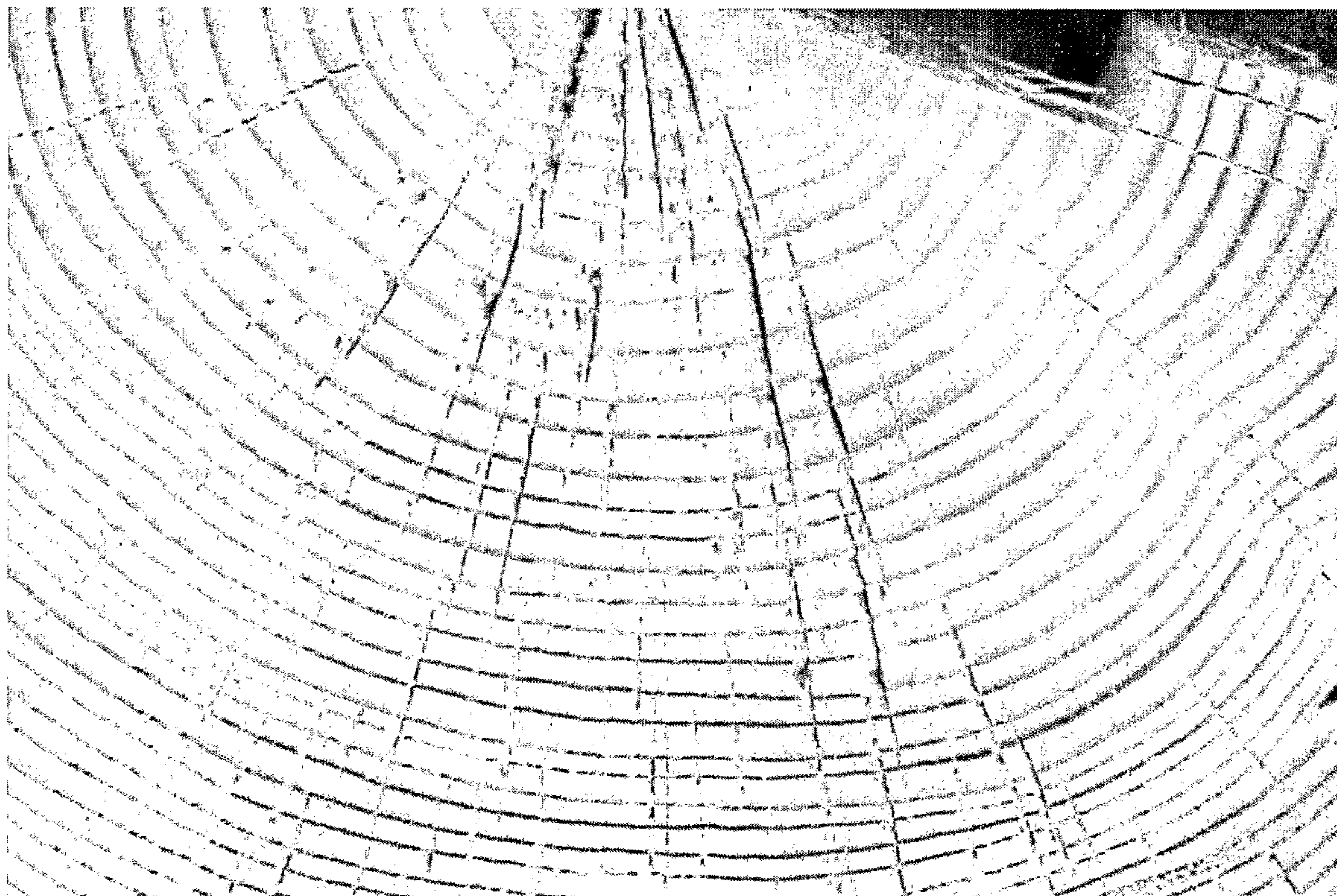


FIG. 4

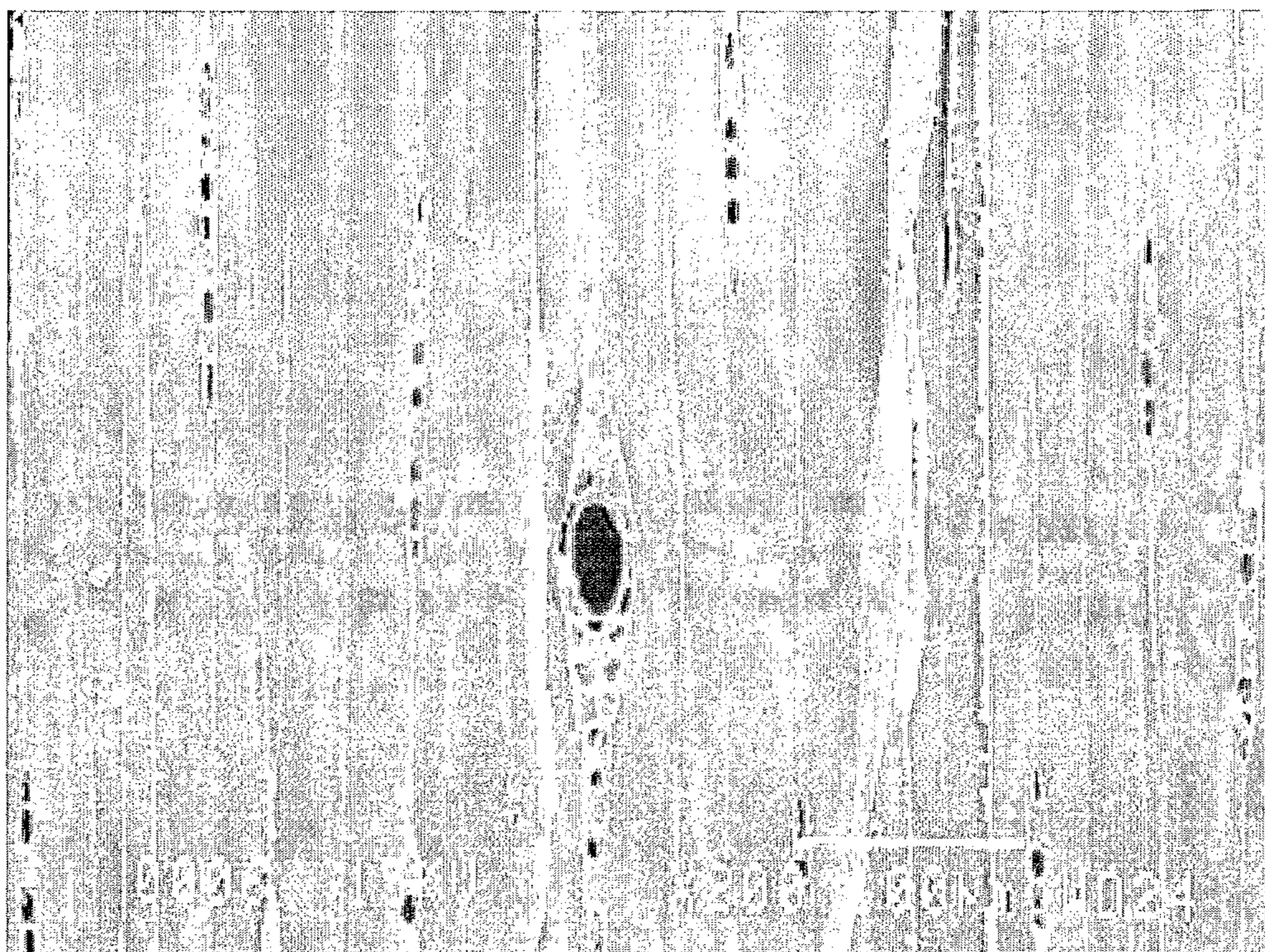


FIG. 5

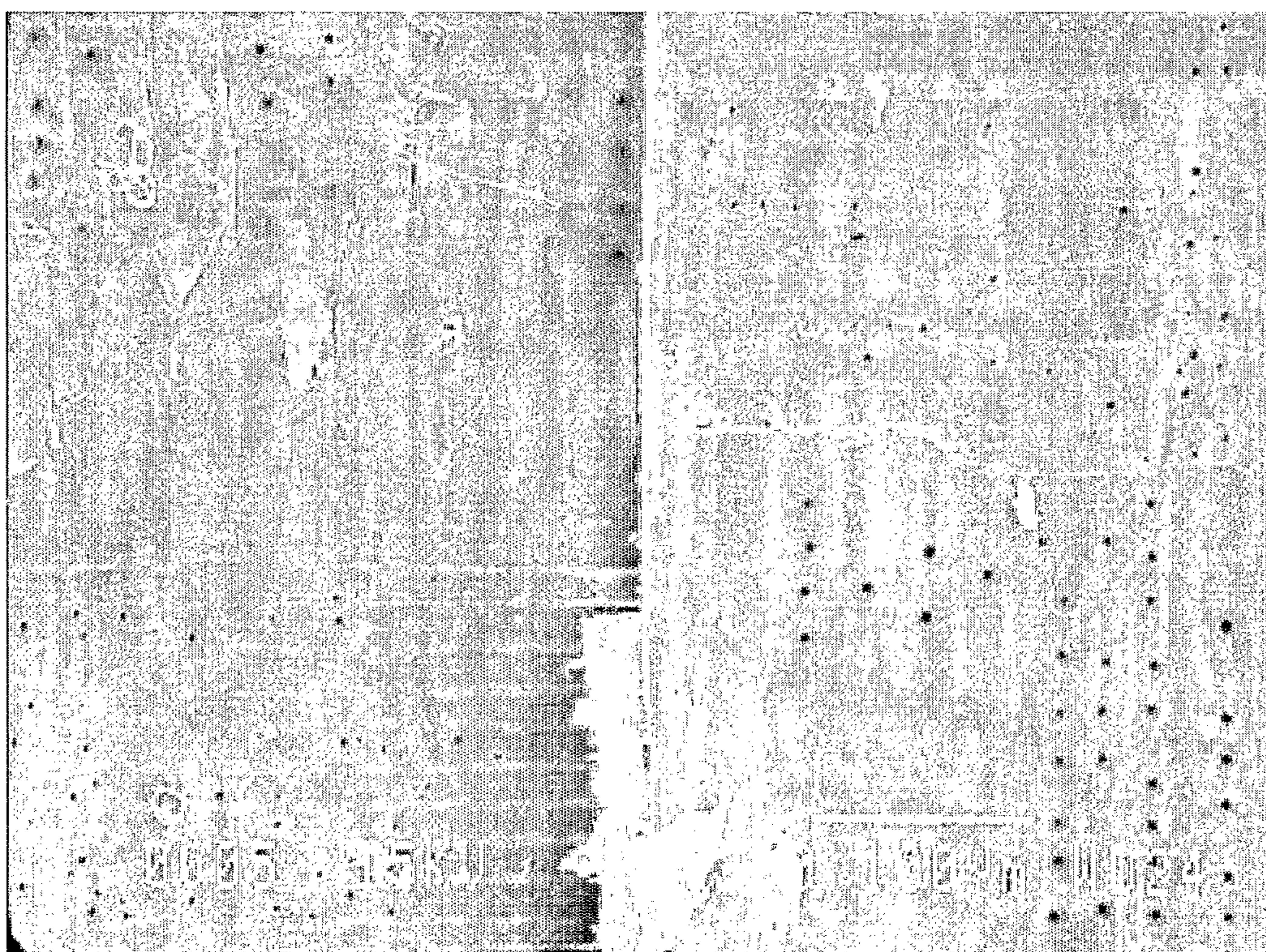


FIG. 6

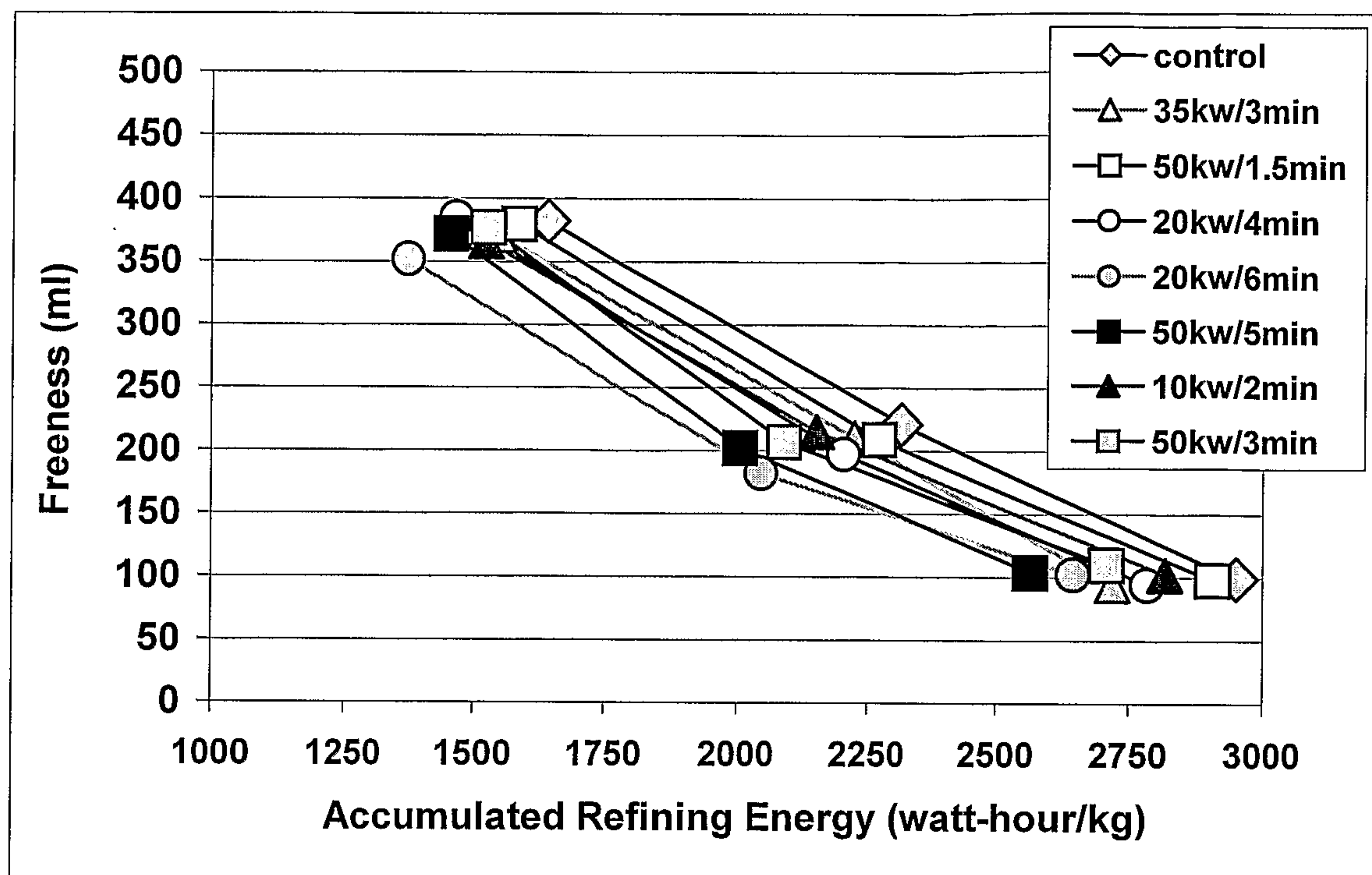


FIG. 7

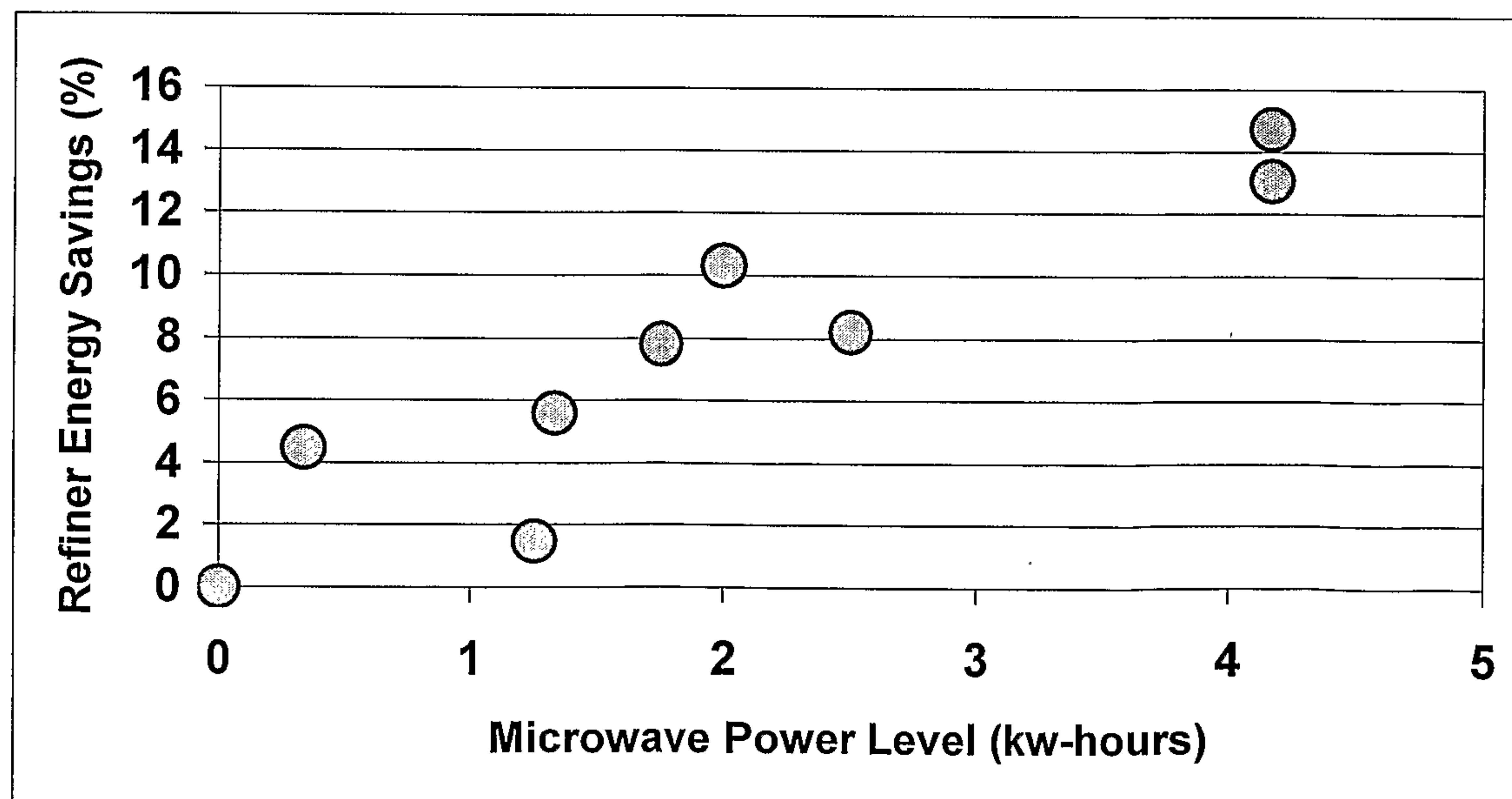
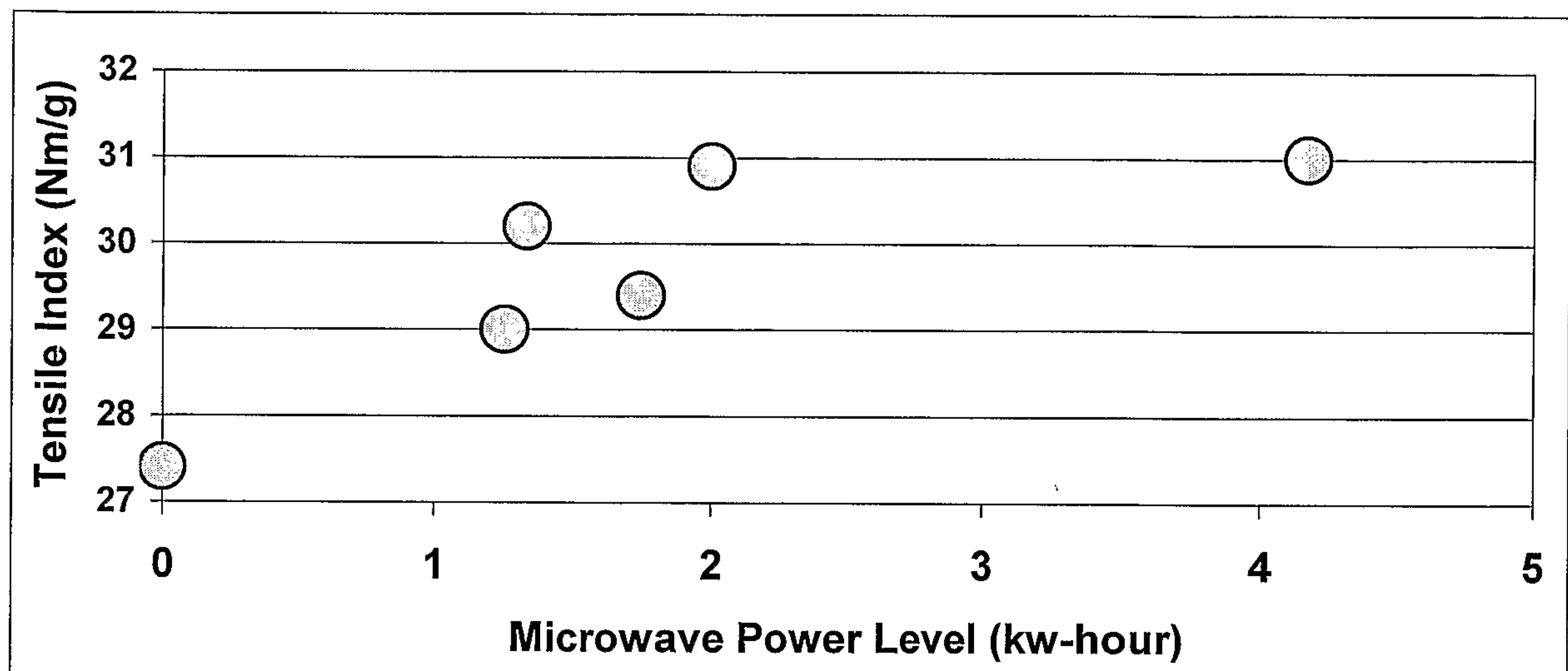
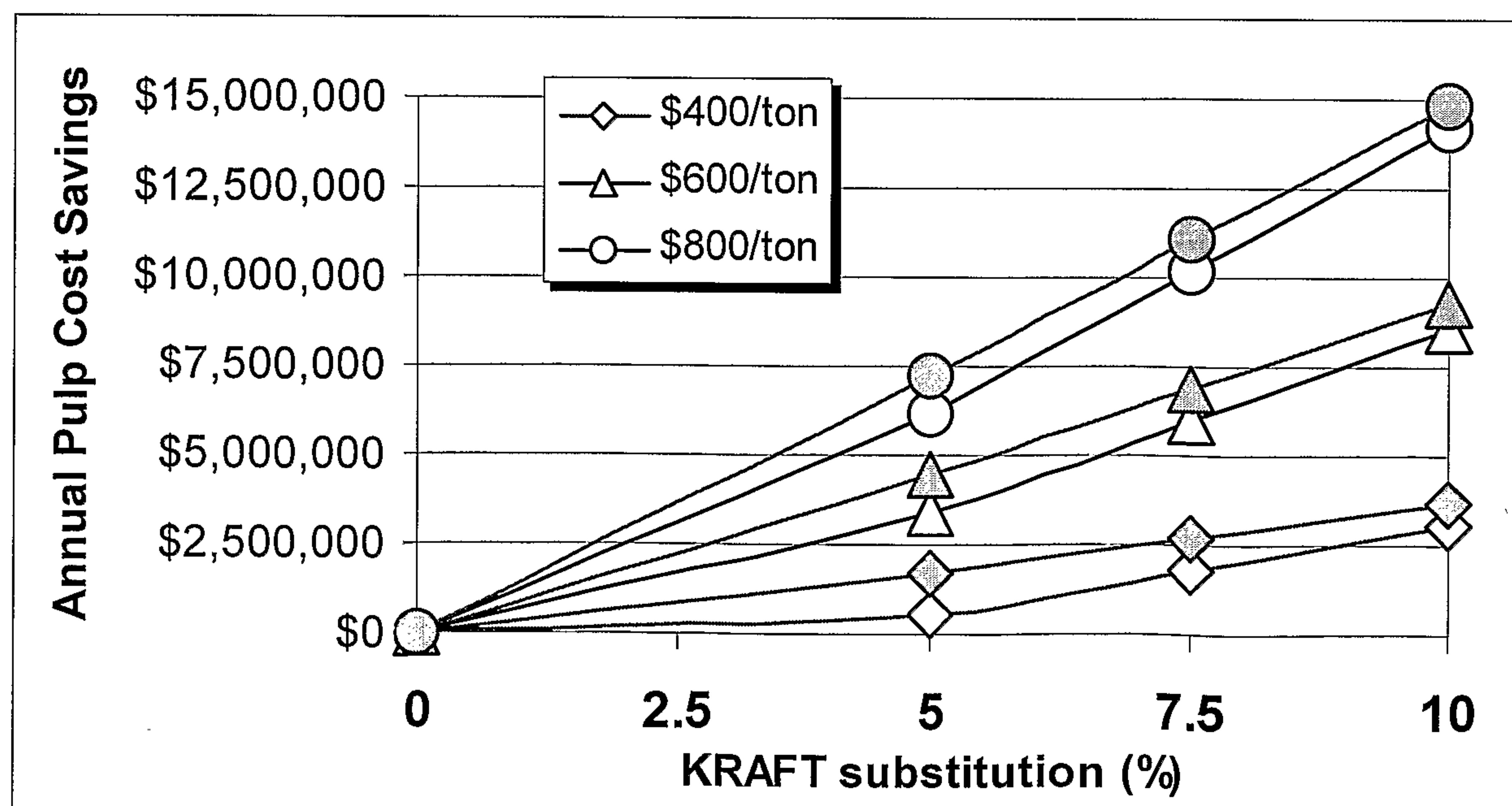


FIG. 8

**FIG. 9****FIG. 10**

