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Introduction

The notion of applying microwave heating technology to consumer laundry appliances was first proposed over a quarter century ago. For many years since, the economic and technical feasibility had been investigated by various groups, but major appliance manufacturers were reluctant to pay any attention to these efforts until concerns regarding cost and safety had been addressed. Recent advances in the enabling technologies for microwave clothes dryers have mitigated most or all of the concerns, resulting in serious interest in developing these appliances for the consumer market.

Historical Background

The first known documented conceptualization of a microwave tumble dryer for fabrics was in the mid 1960's by Levinson.[1] Shortly thereafter a patent assigned to General Electric Company indicates early interest from a major appliance manufacturer.[2] During the mid 1970's, Maytag Company had also expressed interest in the concept, but both companies declined to pursue product development citing perceived high manufacturing costs and difficulties in overcoming the problem of arcing.[3] Throughout the 1980's various individual and collaborative efforts engaged in the construction and testing of prototype dryers had produced several more patents.

By this time the potential advantages of microwave drying were well documented and easily demonstrated: faster drying, greater efficiency, lower drying temperature and reduced fabric wear.[4,5,6] However, most of this work was conducted using clothing articles and materials that are well suited for microwave drying. The hazards relating to arcing and overheating of the less ideal clothing articles were also well known, but viable solutions had yet to be developed.

In the early 1990's, two research efforts were conducting serious investigations to fully characterize the microwave clothes drying process. With funding from Southern California Edison (SCE), American Micro-Tech, Inc. (AMTI) constructed prototype dryers, based on their previous designs, for testing by an independent laboratory and demonstration to the public and major appliance manufacturers. Tests conducted according to the US Department of Energy's (DOE) test protocol for clothes dryer performance showed 30 percent and 10 percent improvements in overall efficiency compared to conventional gas and electric dryers, respectively.[7] These encouraging results prompted DOE to re-evaluate recently adopted dryer performance standards due to become effective in 1994.

The Electric Power Research Institute (EPRI) launched a multi-phase program in 1990 by contracting with Thermo Energy Corporation (TEC) and JG Microwave to design, construct and test residential, commercial and industrial size dryers.[8,] Two major appliance manufacturers, Maytag and Whirlpool, were involved in an advisory capacity to provide guidance based on real world experience. Specific objectives were to conduct parametric testing for performance optimization, study potential hazards and develop viable solutions to any issue that might impede commercialization.

EPRI Prototype Dryers

The first EPRI prototype dryer was a laboratory microwave/hot air unit capable of full parametric control and data acquisition. Testing of this dryer confirmed most of the earlier claims regarding increases in overall efficiency and reductions in cycle time and fabric temperature. Any one of these characteristics could be optimized by adjusting the process parameters, specifically the amounts of and ratio between microwave and hot air energy input. Optimization was also dependent on the size and type of fabric load. When configured to simulate a residential dryer using 2.5kW of microwave energy and 2.5kW hot air, the results for a typical 3.2 kg load of 50-50 poly/cotton clothes and Turkish towels were 19% faster and 18% more efficient than a conventional electric dryer. However, in the commercial configuration having 6.8kW microwave and 5kW hot air, the results were 58% faster and only 3% more efficient than a conventional electric dryer.[9]

Subsequently, residential and commercial prototype dryers were designed and constructed based on these results. Both were based on similar microwave power delivery configurations utilizing 2M130 magnetrons, full-wave doubler power supplies and waveguide feed without isolator protection. But for operation more like conventional dryers they required a means to terminate the cycle automatically when the clothes had reached the desired dryness. Several methods were investigated for cycle endpoint detection, involving the use of exhaust humidity sensors, fabric moisture contact sensors, cavity field strength probes and fabric temperature opto-pyrometry.

Having observed that fabric temperature and field strength correlate well with moisture content, the most suitable and reliable method utilizes IR thermometry and field strength with a fuzzy logic software control algorithm. Figures 1 and 2 below illustrate the responses of load temperature and field strength for a typical large load in a prototype compact 1kW microwave-only dryer. In this case the change in slope at roughly 1100 seconds into the cycle was relatively rapid, and the prior drop in field strength indicated an increase in the dielectric loss characteristics of the load. The combination of these two effects indicated the need to terminate the cycle quickly after reaching a threshold of 100°F.

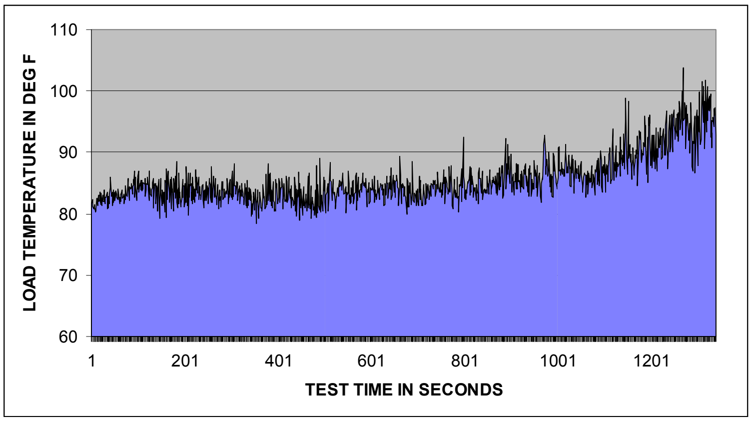

Figure 1, Load temperature vs. test cycle time for 0.7 kg cotton load.

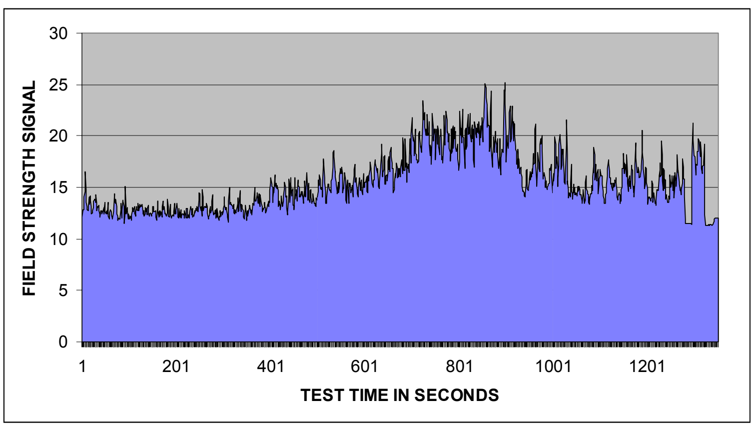

Figure 2, Field strength (normalized) vs. test cycle time for 0.7 kg cotton load

Concerns for potential hazards were addressed by a comprehensive investigation into hazard characterization and detection methods. Most hazards fall into two broad categories, metallic objects such as zippers, threads, clasps, etc. often found in common clothing articles, and “tramp” objects such as coins, cigarette lighters, safety pins, pencils, bobby pins and other materials that might be left in pockets. In most cases, it was found that during most of the drying cycle the electric field strength remained low enough to prevent arcing. However, towards the end of the cycle as moisture neared complete evaporation, the field strength can rise sufficiently to cause arcing. In other cases, such as with metallic threads and pencils, overheating a scorching can occur at any point during the cycle.

A system of selective adsorbent gas sensors was developed to detect minute amounts of pre-combustion vapors in the exhaust stream. Figure 3 below illustrates the rapid sensor response to short bursts of butane. Many different hazard types were tested, and in all cases the system was able to terminate the drying cycle long before open flame combustion would occur. From EPRI's perspective the last of technical barriers to successful commercialization had been overcome.[10] However, it was not possible to prevent fabric damage entirely for all cases, thus the limitations of microwave clothes drying were becoming more apparent.

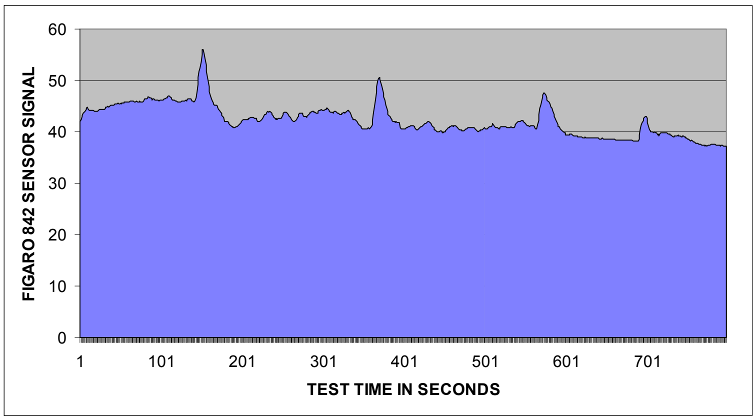

Figure 3, Response of Figaro 842 sensor to short bursts of butane injected into inlet air stream.

Commercial/Industrial Dryers

EPRI investigated commercial and industrial markets for microwave clothes dryers by assessing their economic viability.[11] Since capital cost was perceived as the main obstacle, preliminary designs for large scale dryers were developed. Other economic factors taken into consideration include the impact of improved throughput on overhead costs, energy and maintenance costs, and savings from extended fabric life. Comparing only the cost factors of 125-pound (dry load weight) microwave and conventional dryers, the costs per load are US$1.97 and US$0.89, respectively, or a ratio of 2.2:1 which is hardly attractive to any commercial or industrial user.

However, when savings from extended fabric life are considered, a return on investment is possible depending on the fabric's usage, increased life and replacement cost. According to the EPRI analysis, low cost items such as towels and linens required at least 15% improved life for a 2-year ROI, whereas high cost items such as clean room suits yielded a ½-year ROI with as little as 2% extended life. Other examples of high cost fabric items for which early commercial success is most likely are amusement park entertainer uniforms and airline seat covers.

Market Research

EPRI's project included extensive market research to obtain feedback from consumers and industry. Numerous focus groups and interviews were conducted with consumers, commercial users, retailers, energy companies, government officials and manufacturers. Results indicate consumer interest in the benefits of improved fabric care but an overriding aversion to higher costs. Microwave dryers were unlikely to replace conventional dryers without an added benefit from significant reductions in drying time. However, microwave drying of smaller specialty items was seen as a desirable alternative to dry cleaning, thus a compact microwave dryer appliance was recommended.[12]

Countertop Microwave Clothes Dryer

Following the market research recommendations, EPRI contracted with TEC and Gerling Applied Engineering, Inc. (GAE) in 1997 to develop the concept of a countertop microwave clothes dryer, dubbed "CTMD." GAE designed and constructed several prototype dryers (Figure 4) by merging EPRI dryer technology with well-established microwave oven technology. A primary advantage of this arrangement is the economy of scale already present with the basic half-wave doubler power supply components, thus facilitating commercialization by reducing the costs of materials. Having no direct heat source for convective hot air, the CTMD utilizes dissipated heat from the magnetron and power supply to enhance energy efficiency and provide enough warmth to convey the vaporized moisture without premature condensation.

Figure 4, EPRI Countertop microwave clothes dryer

Further improvements to cycle control and hazard detection were developed, and tests indicated drying rates similar to full size dryers. Demonstrations conducted for several major appliance OEMs and subsequent delivery of prototypes for in-house evaluation have since led to negotiations for technology licensing.[13] The first real indications of product development activity for a residential microwave clothes dryer appliance seem to imply that the barriers to commercialization of this technology may indeed have been lifted.[14]

Some experts in the microwave heating community have doubts about the long term viability of microwave clothes drying while others express optimism by comparing the challenges to those overcome by the microwave oven in its early days. Noting how consumers have accepted and adapted to the microwave oven, the most likely scenario will be an evolution in consumer laundry habits and the birth of an entirely new industry of clothing and laundry products developed expressly for the microwave clothes dryer.

[1] M. Levinson, "Microwave and Ultrasonic Apparatus," US Patent 3,410,166, issued November 12, 1968
[2] D. Heidtmann, "Microwave Dryer Control Circuit," US Patent No. 3,439,431, issued April 22, 1969
[3] "Assessment of Residential Microwave Clothes Dryers," EPRI Report RP2034-35, February 1990
[4] T. Koryu Ishii, "Engineering Analysis of Domestic Size Microwave Clothes Dryers," Journal of Microwave Power, pg. 389-395, Vol. 7, No. 4, 1972
[5] R. Strattan, et al, "Prototype Studies of a Microwave Clothes Dryer," Proceedings of the 26th Microwave Power Symposium, International Microwave Power Institute, pg. 51-52, 1991
[6] M. Hamid, "Microwave Drying of Clothes," Journal of Microwave Power and Electromagnetic Energy, pg. 107-113, Vol. 26, No. 2, 1991
[7] R. Tatum, "Drying Clothes with Microwaves," World & I Magazine, pg. 236, February 1993
[8] "Development of a Microwave Clothes Dryer" EPRI Report TR-102114, July 1993
[9] "Development of a Microwave Clothes Dryer, Interim Report II" EPRI Report TR-103899, July 1994
[10] "Development of a Microwave Clothes Dryer, Interim Report V" EPRI Report TR-106101, November 1996
[11] "Preliminary Design of an Industrial/Commercial Microwave Clothes Dryer," EPRI Report TR-108241, June 1997
[12] "The Residential Microwave Clothes Dryer: Market Potential and Positioning," EPRI Report TR-109116, October 1997
[13] "Countertop Microwave Clothes Dryer," EPRI Technical Brief No. 1006408, December 2001
[14] E. Spagat, "Whirlpool Goes Portable to Sell Dryers to Gen Y," Wall Street Journal, June 4, 2002