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Technical Assessment of Safety for Hair Dryer/Stylers

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Product Safety Engineering Section
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
Edward O. Vetter, *Under Secretary*
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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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for Hair Dryers/Stylers

Introduction

The hair dryer/styler is a relatively new small electrical appliance. In the current marketplace the product generally consists of a plastic case into which a heater, a rotor and a motor are fitted. The motor may be activated either by alternating current (ac) or by direct current (dc). The motor generally is connected across part of the heating element (resistor) circuit. If it is a dc motor, there will be a solid state rectifier built into the input circuit, which in turn is connected in parallel to a part of the resistance (heating element) in order that the electrical potential across the motor will not exceed that required by the motor which is approximately 30 volts. The heating element is made of high resistance metal wire or ribbon which is wound over sticks or strips of high temperature insulating materials, such as asbestos, mica or ceramics. The heating element is connected to a selecting switch which controls the ac line power input to the product. There is a temperature limiting (T.L.) device connected to the heating circuit and is generally located either at the center or the edge of the heating net-work. When the hair dryer is overheated and the T.L. device reaches the pre-set temperature, the device is activated to turn off the power circuit for the whole unit. In addition to the T.L. device, some of the units contain a backup device such as 'fusible link' which will limit the hazardous temperature in the event that the T.L. device fails.

Under normal operating conditions the motor drives a fan rotor which blows air over the heated element, and the warm air is discharged for hair drying or styling. This appears to be a very efficient small appliance. Because of its handiness, convenience, and efficiency, it has become a very popular product as indicated by AHAM's estimated domestic consumption; about 8.5 million units/year in the period of 1973-1975. However, because of this high volume consumption, substandard products may appear in the highly competitive market, and a high injury trend from this product has already been reported; the CPSC "FACT SHEET," September 1975, shows that "nearly 780,000 hair dryers. . . may be a substantial product hazard." Furthermore, "The Commission estimates that last year (1974) nearly 1000 individuals were treated in hospital emergency rooms for injuries associated with hair dryers." Clearly, there are problems associated with these products.

Based on the analyses of two previous reports, one by Mary Stefl 1/ and the other by the author 2/, the potential hazards associated with hair dryers have been identified, viz., electrical, mechanical and thermal hazards. The present study is to investigate the technical problems associated with those identified hazards. With a clear understanding of those technical problems and with the aid of human factors assessment, corrective measures for addressing these hazards may be recommended.

Hazard Potentials

There are three general hazards associated with hair dryers; namely, electrical, mechanical and thermal hazards 1/ & 2/. These hazards may occur separately or combined, they may also occur directly or indirectly. In any event, the control of an individual hazard potential will be an effective measure for safety. Thus, to control leakage current and dielectric breakdown in accordance with the requirements of UL or ANSI standards is a good practice for electrical safety, and to eliminate sharp edges and sharp points by following the guidelines of the NBS reports 3/ & 4/, will reduce the mechanical hazards.

In regards to thermal hazards, two effects need to be considered; one is thermal burn and the other is fire hazard and/or an induced electrical shock or sparks. The control of thermal burn may be accomplished by limiting the output air temperature measured as surface temperature on human skin in accordance with the theory of convective heat transfer. The limit of this surface temperature may be determined from the author's previous study 5/, 6/ & 7/, which discussed how the injury relates to temperature, time and depth of human tissue.

Fire hazards and/or the induced electrical shock or sparks could be caused by excessive heat accumulation inside the casing. The control of this hazard may be achieved by limiting the heat generation or by dissipating it at a faster rate. Of the last two control processes, the former may be accomplished by a sensitive thermal cut off device and the latter, by increasing the flow rate of air. Based on these guidelines for controlling hazards, improved safety measures for the product may be recommended.

It should be noted that there are human factors related injuries, such as electrocution, fracture and strain/sprain reported in the NEISS injury data. Because such injuries do not appear to be specifically product related and there appears to be no feasible technical solution to these problems, they are not addressed in this study.

Technical Evaluation

In view of the analysis and the literature cited in the preceding section, it is understood that only the safety limits for human resistance to injury are known. It is necessary, therefore, to provide methods or tests to screen out hair dryer/stylers having excessive physical force/energy so that the hazard potential associated with the product can be controlled or eliminated. Since some of these hazards occur in a normal operation of the product and some are hidden as induced effects which may occur with possible abuse of the product, a series of tests and measurements were conducted so that apparent hazards could be screened out and the origin of the hidden ones detected.

Materials

One pair each of fifteen makes of hair dryer/stylers were purchased randomly from the open market. Seven pairs of these were of the gun type having round openings for the air outlet. These are commonly referred to as hair dryers, and are generally sold without attachments other than a nozzle. Another seven pairs were of the so called hair styler type having rectangular openings for the air outlet and for comb or brush attachments. The remaining pair was of the dryer/styler type having round openings for the air outlet and for comb or brush attachments. One of each pair was used for destructive tests and the other for nondestrictive tests.

Test Setup and Procedure

The following tests were conducted on selected samples of the above hair dryer/stylers:

1. Careful inspection for workmanship
2. UL "leakage current" and "dielectric breakdown" tests
3. UL cycling test
4. UL temperature tests which include: a) outlet air temperature and b) surface temperature. Both a) and b) were performed with and without cheesecloth to cover the air intake opening.
5. UL drop test with two additional heights, 4 and 5 feet, included for comparison.
6. UL cord strain relief pull test.

Procedures for these six tests, except for the first are described in UL Standard 859, 1975. The first test was aimed at detecting any obvious defects both inside and outside of the samples, such as: a) sharp points or edges on the outside surface, b) metallic surfaces on the outside of heating element enclosure, c) electrically live metal parts exposed outside the casing, d) poor electrical connections inside the casing, e) inadequate clearances between the casing and the heating element or rotor, f) poor rotor mounting, and g) poor location of the T.L. device.

In addition to these six tests, two other series of measurements were performed to ascertain the adequacy of thermal safety requirements for the product. These were:

1. Measurements of heat flux at a distance of 2.5 cm from the air outlet. A calibrated heat flux meter, made by Medtherm Corp., Huntsville, Ala., was employed and a thermocouple was located adjacent to the meter. A hair dryer/styler was held 2.5 cm

(1 in.) away from the meter and hot air was blown onto the meter until the latter reached its steady state. The EMF's of the meter and of the thermocouple were recorded and were converted to heat flux and temperature, respectively. This measurement was repeated for three different hair dryer/stylers.

2. Measurements of outlet air temperatures as a function of air flow rates, and the temperature near the surface of the temperature limiting device. The setup for these measurements is shown schematically in figure 1.

   The orifice flow meter was made in accordance with the principle described by the ASME Report on Fluid Meters, 1959 8/. A No. 40 (.005 in. diam.) chromel-alumel thermocouple, T.C. 1, was inserted across the pipe at a distance of 2.5 cm (1 in.) from the air inlet, which was connected at connection 3 to the outlet of a hair dryer with a round opening. The orifice disc was interchangeable at the connection 1, with three different orifice sizes 1/4, 1/2 and 3/4 of the inside diameter, D, of the pipe, which was 4.3 cm. Connection 2 was used to connect the flow meter with the hair dryer so that measurements of the out flow air temperature at 2.5 cm away from the outlet could be accomplished with and without the flow meter connected. Another thermocouple, T.C. 2, was located at the vicinity of the T.L. device. One pressure tape was located at 1 D upstream from the orifice and a second tap at 1/2 D downstream from the orifice. A U-tube manometer filled with water was connected to the taps to measure the pressure difference. The power input line of the motor was disconnected from the heater circuit and joined to an independent ac or dc source as required, so that the speed of the motor could be controlled.

   In the case of rectangular opening hair stylers, connection 3 was modified to a rectangular funnel, across which three thermocouples were installed, to accommodate the two different openings. Otherwise the rest of the setup was the same as described above.

   The procedure of measurements was as follows:

   A. Before the motor was disconnected:

      1. Connection 3 was attached and connection 2 was detached, i.e., separated from the flow meter. The hair dryer was turned on and the steady state temperatures of T.C. 1 and T.C. 2 were recorded.

      2. The orifice disc was removed from connection 1. Connection 1, 2 and 3 were attached. The hair dryer was turned on and the temperature of T.C. 1 and T.C. 2 was recorded as in (1).

3. The orifice disc of size 1/4 D was installed in connection 1. The hair dryer was turned on and temperature recorded as before. The pressure difference from the two manometer arms was also recorded.

4. The orifice disc of size 1/4 D was replaced with 1/2 D, and then 3/4 D. For each orifice disc, the temperatures and pressure differences were recorded.

B. After the motor was disconnected:

The motor was joined to an independent power supply. The voltage was adjusted to the lowest integral value which would drive the motor and increased in four to five equal increments to the maximum allowable integral value for the motor. At each selected voltage level, steps 2, 3 and 4 of procedure (A) were repeated.

C. Procedures (A) and (B) were repeated for three different hair dryers and three stylers.

Results and Calculations

The results of the tests and measurements are listed in the following tables. The first six tables are self explanatory. In tables VII and VIII, the flow rates were calculated in accordance with the principles given in ASME Report on Fluid Meters, 1959 8/. The derivation is given in the appendix. Values in tables IX and X are output air temperatures under various conditions. Temperatures measured adjacent to T.L. device are listed also in table X. In table XI, the heat absorbed by the heat flux meter was computed in accordance with the calibrated value given by the manufacturer.

It should be noted that the remarks in table I are the results of observations, and those values and remarks in tables II to VI are the results of UL standard tests. The apparent adequacy of these tests will be discussed in the next section.

The accuracy of flow measurements depends upon the geometry of the setup and the accuracy of the manometer. In order to ensure the reliability of the measurements, two more pressure taps (not shown in figure 1) at 2.5 D and 8 D from the orifice for upstream and downstream air flow, respectively, were installed to measure the pressure drop. The results were consistent. Since these measurements were intended for trend rather than accuracy, no effort to refine the measurement technique was exercised. It was estimated that the total experimental uncertainty was about ± 10% (higher for low values and lower for high values).

The heat flux measurements were aimed at determining the quantity of heat that would be received by the human body if the air output of a hair dryer/styler was blown directly onto it. The 2.5 cm distance used in these measurements was based on Stefl's study on human behavior 1/. Because the heat flux and the surface temperature depend on the flow characteristics, the uncertainty in these measurements is also estimated to be about ± 10%.

Discussion

In evaluating the results of the first six tests, each test will be discussed here for its apparent adequacy or deficiency in addressing the commonly identified hazards. The results of the last two laboratory experiments are primarily related to thermal hazards which appear to be one of the more common problems associated with hair dryer/styler. A detailed discussion of these results is also included later in this section.

The first inspection was subjective in nature and only qualitative evaluations can be given. In general, no sharp edges or points were found on the surface of the casing of any of the hair dryer/stylers examined, except on the attachments to the stylers. Some of those combs and brushes felt somewhat sharp to the hand, especially in a combing motion. There was no obvious exposure of metallic surface on heating element enclosure except three minor cases. No obviously defective electrical connections were found.

Some undesirable characteristics associated with a few hair dryer/stylers were noted. One was related to the mounting of the rotor unit in the casing, where the clearance between the rotor blades and the casing was too small, or the fit of the rotor shaft in its bearings was too loose. The other was associated with the T.L. device in which the contacts for opening and closing the circuit were not functioning properly. Any one of these undesirable characteristics with a slight malfunction could lead to a thermal hazard.

There were three actual cases 9/ of overheating which were caused by the characteristics stated above. In one case the rotor blade was broken, and a small piece of plastic was stuck to the heating element causing smoke to be emitted. This was caused by the rotor shaft moving slightly off its axis causing the blade to contact the ridge inside the casing. In a second case, hair fragments and dandruff or oily dust were accumulated between the shaft and the casing. The motor slowed down, and enough heat built up to melt the enclosure of the heater portion of the casing. In a third case the contact of the T.L. device was neither completely closed nor opened, which allowed enough current to energize the heating element but not enough to operate the motor. As a result, heat built up and the plastic at the opening melted.

All of these defects are design problems which can be corrected. From the standpoint of safety performance, if those products had had a sensitive T.L. device, properly installed, the last two malfunctions described above could have been avoided.

The results of the next five UL 859 tests are shown in tables II-VI. The second, third and sixth tests appear to be adequate. The part of the fourth test pertaining to surface tempeature, also appears adequate. The requirements and criteria for these four tests may be used to screen out those substandard products from reaching consumers. The other part of the fourth test pertaining to the outlet air temperature, however, involves human thermal resistance and the acceptance criteria appear to be questionable. This is discussed in the heat flux measurement section of this report.

There are two problems involved with the drop test; the recommended drop height and the subsequent acceptance criteria. The criteria call for electrical operational acceptability but does not include requirements for thermal acceptability. It can be seen from the results of the drop tests that in some cases the rotor shafts were shifted, blades were broken, and heating elements were dislocated. Any of these could present a hazard if the product is to be used repeatedly. The test drop height of three feet does not appear to cover common occurrence of usage. A consumer more often uses the product while standing 1/, and the height of the product at that point would be about five feet. For a more realistic test the drop height might be increased to five feet, even though the test results show that at three feet, three out of five samples passed the test, and at five feet only two passed.

Flow Rate and Air Temperature Measurements

The results of these measurements are listed in tables VII-X. Table VII shows the flow rates at various restrictions with the motor operated at normal voltage. These data are plotted in figure 2. The flow restriction, β, is the ratio of the opening diameter of the orifice to that of the pipe, and the pipe diameter is approximately equal to that of the opening of the hair dryer/styler, so that at $\beta = 1$, the extrapolated values for Q, the flow rate, may be taken to be the flow rate of the hair dryer/styler without restriction. It may be noted from figure 2 that the measurements for the sample gun type hair dryers yield practically an identical higher flow rate, whereas those for the hair stylers are varied and are generally lower. In the latter case, the lower flow rate appears to be caused by a less efficient rotor working against the restriction of the opening. Further restriction by attachments such as comb or brush, would reduce the flow rate further and possibly increase heat as shown in table X.

Table VIII shows the values for flow rates at various power inputs to the motor. The speed of the motors generally used in these products is a function of torque that the motor encounters as well as the voltage input to the motor. Therefore, the voltage on the motor can be varied to give the equivalent effect of increasing the torque loading. In practical use, the accumulation of hair fragments and dandruff or dust can increase the applied torque and slow down the speed of the motor, thereby reducing the flow rate of air. The last factor will influence the output air temperature which is demonstrated by these values shown in tablex IX and X and in figure 4.

In table IX, the thermal cut-off temperatures for samples D2 and S2 at high flow restriction ($\beta = 0.265$) are lower than those at a lower restriction. This illustrates the fact that the T.L. device is sensitive to heat rather than temperature. At higher flow restriction the air flow rate is lower as shown in figures 2 and 3. This also means that the volume of air remains in contact with the heater longer, which in turn heats up the T.L. device faster. If the heat capacity of the T.L. device is comparatively low, less heat will be required to activate the device to cut off the circuit as these two samples showed. On the other hand, if the heat capacity is high, the heat required for the device to cut off the circuit will be greater. Also, the output temperature increases greatly as indicated by sample D1 in the same table.

It should also be noted that in table X, T_d columns are for the temperatures adjacent to the T.L. device at the indicated output air temperature, T_a. The values for T_d are lower than the output temperatures and change much more slowly. The two temperatures vary by a factor from 2 to 4. These observations further indicate that the T.L. device is sensitive to heat rather than to the temperature of the surrounding media. In other words the heat capacity of the T.L. device is too high. This point may be appreciated further by the observations of the time lag required for the T.L. device to operate. In some cases, this took as long as 5 minutes. During this time the heat build up inside can become highly destructive. Two of the samples used in this experiment were damaged during the test. (Note that 1000 watts of heat generated for 5 minutes without dissipation is equivalent to 300,000 joules or about 300 Btu inside the casing.)

These observations indicate what appears to be a basic problem. The corrective measure is really dependent upon engineering design. However, if the problem of energy consumption and the efficiency of performance is immaterial, and only the safety performance is to be considered, then a sensitive temperature limiting device, properly installed and calibrated, would eliminate this particular problem.

Heat Flux Measurements

The results of these measurements are shown in table XI, where two types of values are tabulated. One is the value for heat flux which would be received by the human body if hair dryer/styler at a distance of 2.5 cm blows air directly onto it, the other is for temperature adjacent to the heat flux meter which would be the temperature of hot air imparted to the human body. The values for heat flux are steady state values which were reached within about one half of a minute from the start.

It is of interest to note that in table XI the surface temperature for sample S4 is higher than that of the other two samples by about 30 C, and yet the heat flux value for the same sample is lower. This appears to be inconsistent, but it is not uncommon for convective heat transfer in turbulent flow. In turbulent flow convective heat transfer depends on many factors such as the shear stress, the velocity and the properties of the fluid and the geometry of the flow system. Any variation of these parameters will affect the temperature distribution and the heat flux. The complexity of this problem is beyond the scope of this study. However, since the three samples tested had significant differences in the size and shape of output openings, the size and location of heating elements, and the geometry of protective grids in the outlet air stream, the variations in heat flux and temperature values shown in table XI are not unreasonable.

Since safety is the concern of this investigation, the physiological effects to hair and skin by heat and temperature should be considered first. According to the Wool Handbook 10/, the physical and chemical properties of human hair are very similar to animal hairs which have been studied extensively by the wool industry. In these studies it is shown that if wool is subjected to a wet heat about 100 C, it will lose most of its resistance to deformation and become more plastic. It will no longer return to its original length. Moreover, it may even become brown and brittle with a reduction in its breaking strength. The utility of the hair dryer/styler is for drying/styling hair, but it is obviously undesirable in the drying process to have hair damaged. Therefore, the temperature of hot air blown onto moist hair should preferably not exceed 100 C.

Secondly, if the hot air is blown onto skin directly, the surface temperature of skin is drastically modified. According to the theory put forth by Buettner 11/,

$$T_s = T_o + 2H \quad t/\pi\lambda \qquad (1)$$

where T_s = surface temperature of human skin after receiving heat from hot air, C.

T_o = original surface temperature of human skin, C.

H = heat flux, watt $\quad cm^{-2}$.

λ = $k\rho c$, thermal inertia, joule$^{2} \quad s^{-1} \quad cm^{-4} \quad C^{-2}$, where k is thermal conductivity; ρ, density; and c, specific heat, of human tissue.

t = time, s.

Substituting 35 C for T_o, and 0.0228 $J^2/(cm^4 \quad s \quad C^2)$ for λ into equation (1), it yields

$$T_s = 35 + 7.48 \, H \quad t \qquad (2)$$

It is seen that the surface temperature, T_s, is a function of the heat flux the skin receives and the time of exposure. However, because of the human tolerance limit to thermal energy, the freedom of each of these variables is restricted. Moreover, because the thermal energy is limited to within the physiological tolerance, either of the two sets of variables, i.e., temperature-time and heat flux-time may determine the criteria for thermal safety. Moritz and Henriques 6/ have determined the temperature time relationship for skin injury, and Stoll 7/ has measured the heat flux-time limitation for safety. Both of these experiments were performed on human subjects. Their results are reproduced here for reference and are shown in figures 5 and 6, respectively.

The results shown in table XI for hair dryer/stylers may be compared with either figure 5 or 6. It is apparent that either the surface temperature or the heat flux is too high, if hot air from a hair dryer/styler is blown directly onto human skin, such as forehead or neck. Note that of the surface temperatures in table XI, the first two are approaching and the third one is over, the injurious limit; even the values for heat flux fall into a rather narrow range of tolerance time, 15-20 seconds beyond which blisters would form. Of course, the use of hair dryer/styler is to dry/style hair and hair may act as an insulator to the skin. Also, the appliance is usually kept in motion during use, in which case no skin surface temperature would reach the steady state values observed in table XI. However, in some situations, where the attached comb or brush becomes entangled in the hair, or the appliance is used for drying/styling a child's hair by an adult, the duration of exposure may extend well beyond the time limit required by figure 5 or 6, and thermal injury may result. Therefore, for the sake of safety, the limits for the surface temperature and the heat flux should be chosen in accordance with figures 5 and 6, respectively.

Conclusions and Recommendations

In view of the test results and the performance characteristics of the hair dryer/styler, the apparent causes for the three general hazards associated with the product may be evaluated technically as follows:

1. Electrical Hazards. If a product has met the requirements for the leakage current and dielectric breakdown tests the product should be reasonably safe. However, there is an induced hazard to be considered. In the event of reasonable and foreseeable abuse, such as when the hair dryer/styler is dropped to the floor, there may be no apparent failure on the outside, and yet the inside wiring or heating element may be dislocated in such a way as to create an electrical hazard. It is recommended, therefore, that the hair dryer/styler should be subjected to the drop test first, then to a limited cycling test (UL859-26.28) and then to the leakage current and dielectric breakdown tests. This test sequence should be effective in reducing those electrical and thermal hazards that are mechanically induced.

2. Mechanical Hazards. Mechanical injuries associated with hair dryer/stylers were approximately 30% of those reported by NEISS in 1974-1975, and yet there was no in depth investigation report (IDIR) for any of these cases. From the performance point of view, in normal use or even reasonably foreseeable abuse, it is difficult to visualize how these injuries would occur, since the results of a visual inspection show no apparent sharp points or edges other than those on the attached comb or brush. Even for those, a high force would be required to lacerate human tissue. Perhaps, in combing or brushing thick and tangled hair, such force would be applied and the momentum of this applied force sometimes could cause the attachment to impact onto other parts of the body resulting in a laceration or puncture. If this is the case, any unduly sharp points or edges on all surfaces should be dulled.

3. Thermal Hazards. To control the thermal hazard potential is an inherent difficulty for this small appliance. The heat capacity is low, for the mass is generally small; and yet a huge energy (as high as 1500 watts or approximately 2 horse power) is supplied to some models. It is easy to conceive how such excessive energy (heat) could become destructive. Obviously, thermal control is an essential requirement in order to minimize this hazard. The higher the thermal energy generated, the more difficult the control process becomes. Since the hair drying/styling process depends upon the convective heat transferred to the hair, the efficiency of the process depends more on the velocity of air flow than on heat. Therefore, the energy input beyond a certain point appears to be unnecessary. The human factors study reported by Stefl 1/ has demonstrated that the average time for the hair drying/styling process is 7 minutes with no apparent trend related to the power input to those hair dryer/stylers used in the study (from 200 to 1100 watts). On the other hand, the high powered hair dryer/styler is not necessarily a high risk product if the control mechanism is adequate.

   There are three control mechanisms which should be considered:

   A. Temperature limiting control - this control should limit the heat accumulated inside the casing as well as the output air temperature. Inside the unit the heat accumulation should be prevented from reaching a destructive point, such as flashing, melting or flaming of those material with low thermal resistance. The output air temperature should be limited to avoid thermal damage to hair and/or to skin tissue. Since the power input is usually large, the heat accumulation is rather rapid if the heat dissipating process is slowed down. Therefore, the temperature limiting device should be calibrated in accordance with the maximum allowable output air temperature. Based on the results shown in table X, the devices investigated were not set for the output temperature. In some cases this temperature reached about 200 C before the power was cut off. Furthermore, even for inside temperatures many of the devices did not respond fast enough. In some cases, when the motor was slowed down the heat accumulated for 3 to 5 minutes and reached a destructive point, causing the casing to soften before the device was activated. This means that the response time of the T.L. device was too slow. Therefore, the temperature limiting mechanism or device should be calibrated to limit the air output temperature and also should be sensitive to the heat accumulated inside.

B. Air flow rate for thermal control. The out-flow air temperature of a hair dryer/styler is inversely proportional to the air flow rate, if the power input remains constant. This also is true for the inside temperature in accordance with the theory of convective heat transfer process. Thus, in the interest of safety, an increased air flow rate would increase the efficiency of the drying process and reduce the thermal hazards. This is merely a suggestion since this may involve a design problem. However, if the criteria recommended in A above are to be satisfied, the suggestion here should be considered in order to accommodate the high power input.

C. Thermal insulation. Excessive heat may also be controlled by a process of confinement. Thermal insulation could be used to limit the direction and rate of heat flow, and prevent some low thermal resistance materials such as the plastic casing from being damaged. Again, this is a design problem.

For thermal safety, the first mechanism is to cut off the heat generation before it becomes excessive; a second one is to control excessive heat by a process of dissipation and a third is heat control by confinement. These three mechanisms may be employed separately or in combination to ensure a safer product.

Table I. Visual Inspection

Sample #	Sharp Points	Sharp Edges	Metallic* Surface
S1	No	No	No
S2	No	No	No
S3	No	No	No
S4	No	No	No
S5	No	No	Yes
S6	No	No	Yes
S7	No	No	Yes
DS	No	No	No
D1	No	No	No
D2	No	No	No
D3	No	No	No
D4	No	No	No
D5	No	No	No
D6	No	No	No
D7	No	No	No

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*Metallic surfaces on the outside of heating element enclosure.

Table II. Leakage Current and Dielectric Breakdown Tests

Sample #	Leakage Current	Dielectric Breakdown
S1	Passed	Passed
S2	Passed	Passed
S3	Passed	Passed
S4	Passed	Passed
S5	Passed	Passed
S6	Passed	Passed
S7	Passed	Passed
DS	Passed	Passed
D1	Passed	Passed
D2	Passed	Passed
D3	Passed	Passed
D4	Passed	Passed
D5	Passed	Passed
D6	Passed	Passed
D7	Passed	Passed

Table III. Cycling Tests*

Sample #**	# Cycles	Start Date	Stop Date	Comments
S2	6385	4/22	5/4	Passed
S4	6440	4/26	5/4	Passed
DS	1100	4/16	4/19	Dryer stopped cycling over weekend. Inspection showed two thermal cutoff switches - one was open permanently and one closed. Two small pieces of plastic loose inside the rotor.
		4/19	4/26	
D4	6589	4/19	4/22	Passed
D5	3800	4/19	4/30	Slow cycling, stopped test
D6	1401	4/20	4/22	Dryer made noise. Small particles were blown out through heaters. Leakage and breakdown test - passed. Inspection showed that rotor split on one side. When heated, rotor expanded hitting inside casing. Pieces of plastic broke off rotor blades and blew through heaters lodging in cross bar at the heater element and melted.
D7	6383	4/19	4/27	Passed

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*These tests were performed in accordance with UL859 - Table 31.1 and section 31.4. The "automatically reset control" was interpretted as "temperature regulating thermostat" for the purpose of endurance tests.

**Samples listed here were selected randomly, while other samples were used for other tests.

Table IV. Air and Surface Temperatures*

Sample #	Air Temperature, °C	Outside Surface Temperature of Heater Enclosure, °C
S1	66	81
S5	45	72
S7	75	93
D1	86	-
D2	58	123
D5	67	-
D7	54	-

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*Air temperatures were measured 2.5 cm away from opening. Surface temperatures were measured at the middle circumference, about halfway along the length axis, of the outside surfaces of heater enclosure. In some of the products, there was a thin sheet of asbestos inserted between the heater and the enclosure as thermal insulation. No surface temperature was measured for those products.

Table V. Drop Test

Sample #	Drop Ht. in.	Drop #	Leakage	Breakdown	Comments
S3	36	1	Passed	Passed	Came apart at seam. Two small pieces of plastic loose inside. Rotor blades were broken.
S5	36	3 drops	Passed	Passed	
	48	1	Passed	Passed	
		2	Passed	Passed	
		3	Passed	Passed	Came apart at seam. Rotor stopped - heating element turned red for 6 sec. Unit cut off. Inspection showed rotor did not turn due to bent shaft.
S6	36	1	Passed	Passed	
	36	2	Passed	Passed	Rotor blade bent, hitting inside of case making noise.
S7	36	3 drops	Passed	Passed	
	48	3 drops	Passed	Passed	
	60	3 drops	Passed	Passed	
D4	36	3 drops	Passed	Passed	
	48	3 drops	Passed	Passed	
	60	3 drops	Passed	Passed	

Table VI. Cord Pull Test
(Strain Relief)

Sample #	Passed	Failed	Comments
S3		X	Cord moved inside under load.
S7	X		
D4	X		
D5	X		
D7		X	Cord pulled through strain relief and out of dryer.

Table VII. Flow Rates at Various Restrictions

Sample	Air Flow Rate, Q X 10^3, m^3/s $\beta = 0.265$	$\beta = 0.5$	$\beta = 0.765$	$\beta = 1.0$*
D1	1.98	7.08	11.9	16.7
D2	1.70	6.80	11.9	16.7
D3	2.27	7.36	10.8	16.7
S1	1.13	3.96	6.23	8.9
S2	0.85	2.83	5.10	7.1
S3	1.13	3.96	8.78	11.9

---

*No restriction, values were extrapolated.

Table VIII. Flow Rates at Various Motor Voltages

		Air Flow Rates, Q X 10^3, m^3/s				
Sample	Voltage β	6V	12V	18V	24V	30V
D1	.765	3.90	7.19	10.6	13.3	15.6
	.5	2.52	4.98	6.80	8.27	9.91
	.265		1.22	1.73	2.10	2.61
D2	.765	5.52	9.43	12.5	15.8	
	.5	2.78	5.44	7.48	8.83	
	.265	0.76	1.44	1.92	2.35	

Table IX. Output Temperatures at Various Restrictions with Constant Voltage to Motor

		t°C	
Sample	β = 0.765	β = 0.50	β = 0.265
DS	60	92	(94)*
D1	78	124	(200)
D2	67	122	(100)
D3	56	(124)	(133)
S1	70	(102)	-
S2	72	90	(80)
S3	100	113	-

---

*The value in the parenthesis was the temperature at which the T.L. device was activated and the power was cut off.

Table X. Highest Temperatures, T_a and T_d*, at Various Motor Voltages and Flow Restrictions

Sample		D1		D2		S1		S2	
Volt	β	T_a,°C	T_d,°C	T_a,°C	T_d,°C	T_a,°C	T_d,°C	T_a,°C	T_d,°C
6	1.0	(120)**						(167)	61
	0.765			(96)		149	74		
	0.5			(210)					
12	1.0	115						93	40
	0.765	118		65		78	50	108	48
	0.5	(195)		148					
18	1.0	88						74	36
	0.765	97		54		62	41	85	43
	0.5	171		121					
24	1.0	78						67	35
	0.765	85		49		56	38	76	41
	0.5	147		102					
30	1.0	72							
	0.765	77							
	0.5	135							
As Is+	1.0	64		58	58				
	0.765	78		67	56				
	0.5	124		122	40				

---

*T_a is the output air temperature measured 2.5 cm away from the opening; and T_d is the temperature adjacent to the T.L. device inside a hair dryer/styler.

**The value in the parenthesis was the temperature at which T.L. device was activated and the power was cut off.

+The "As Is" values are those measured before the dc motor was separated from the circuit.

Table XI. Heat Flux from Hair Dryer/Styler Onto Blunt Surface

Sample	Heat Flux		Surface Temperature
	watt/cm^2	(cal/cm^2/S)	°C
D4	0.74	(.18)	65
S1	0.61	(.15)	64
S4	0.57	(.14)	95

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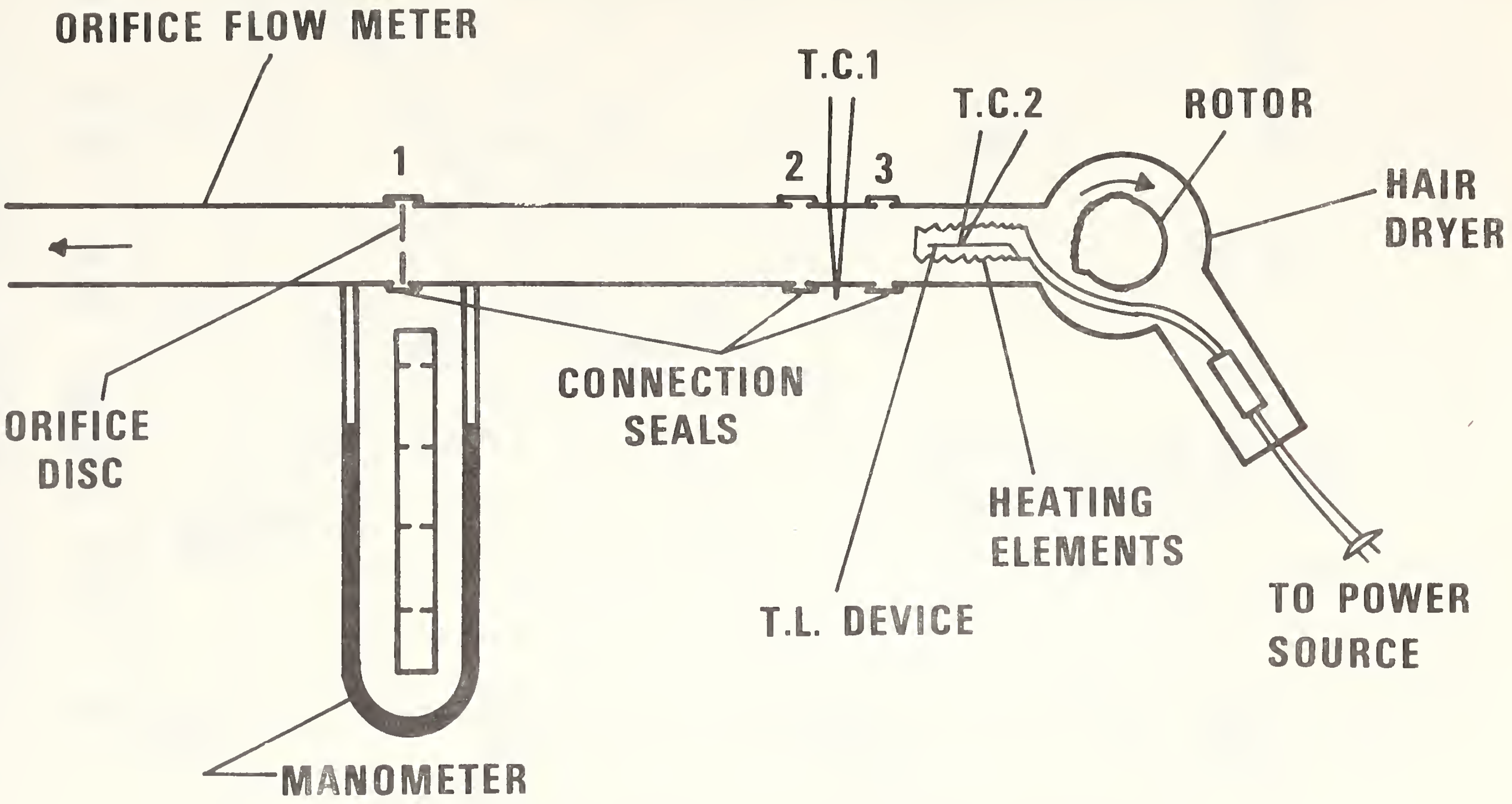

Figure 1. Schematic diagram for temperature and air flow measurements.

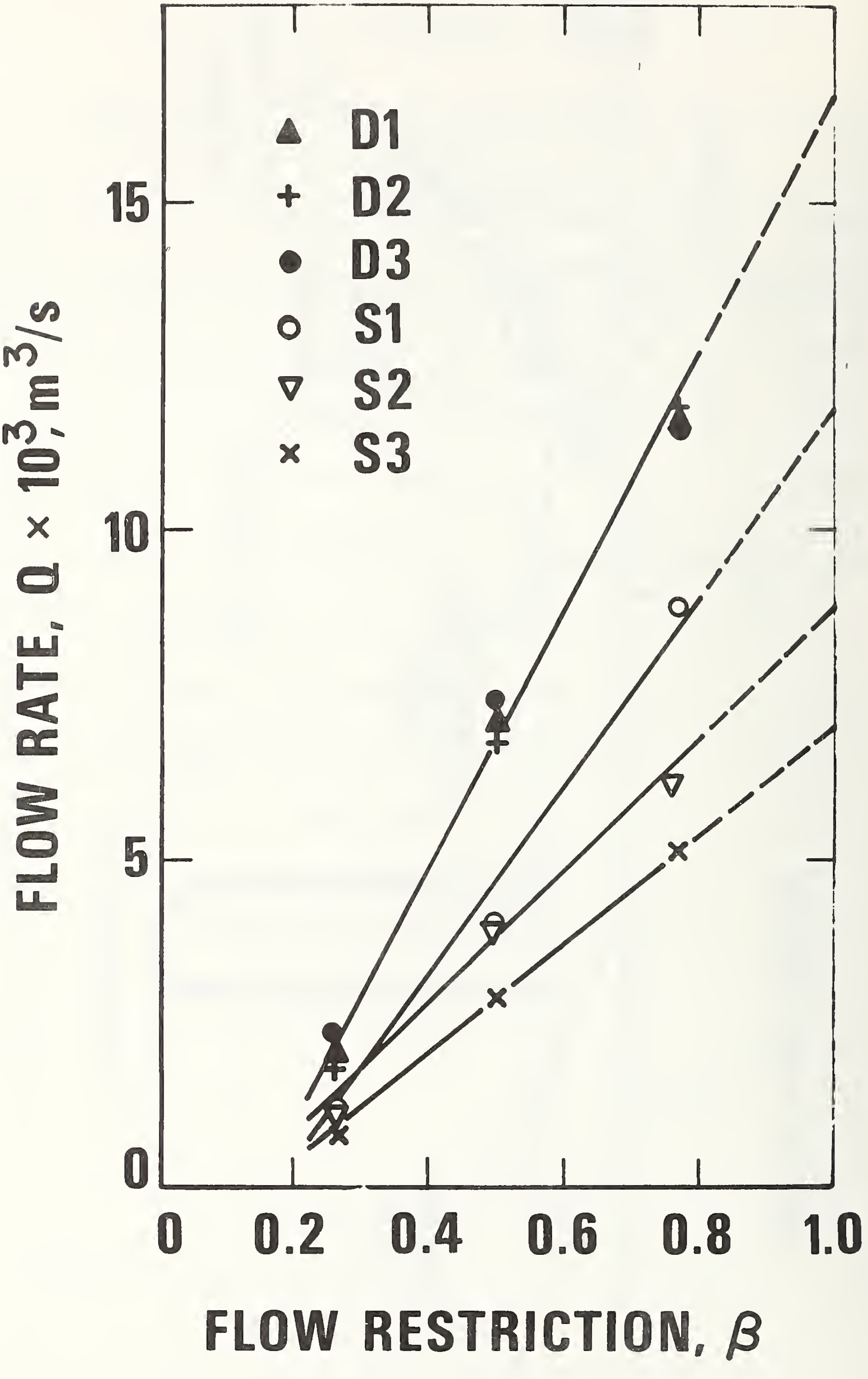

Figure 2. Flow rates versus flow restrictions.

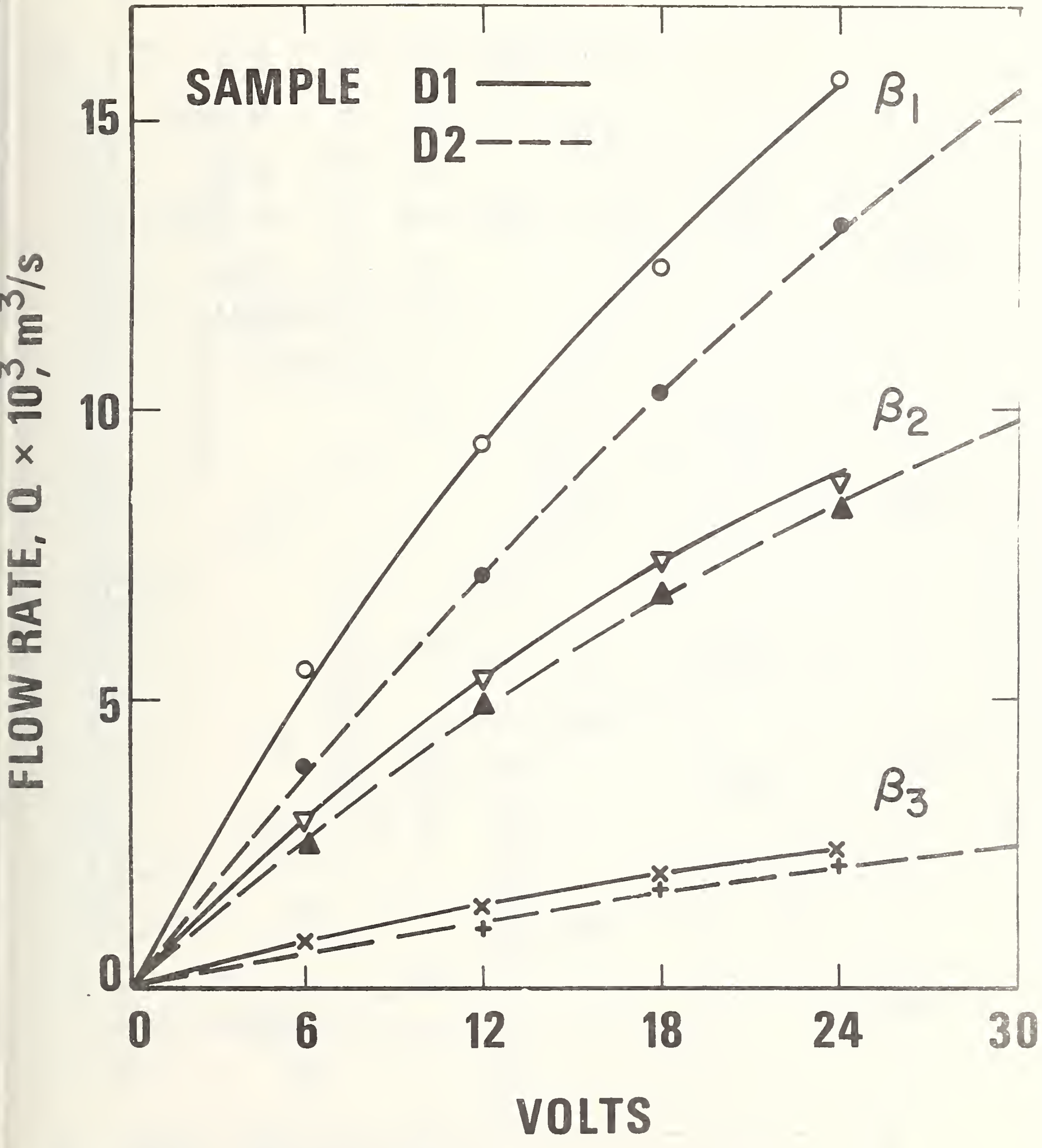

Figure 3. Flow rates at various power inputs and at different flow restrictions: β_1 = 0.765; β_2 = 0.5 and β_3 = 0.265.

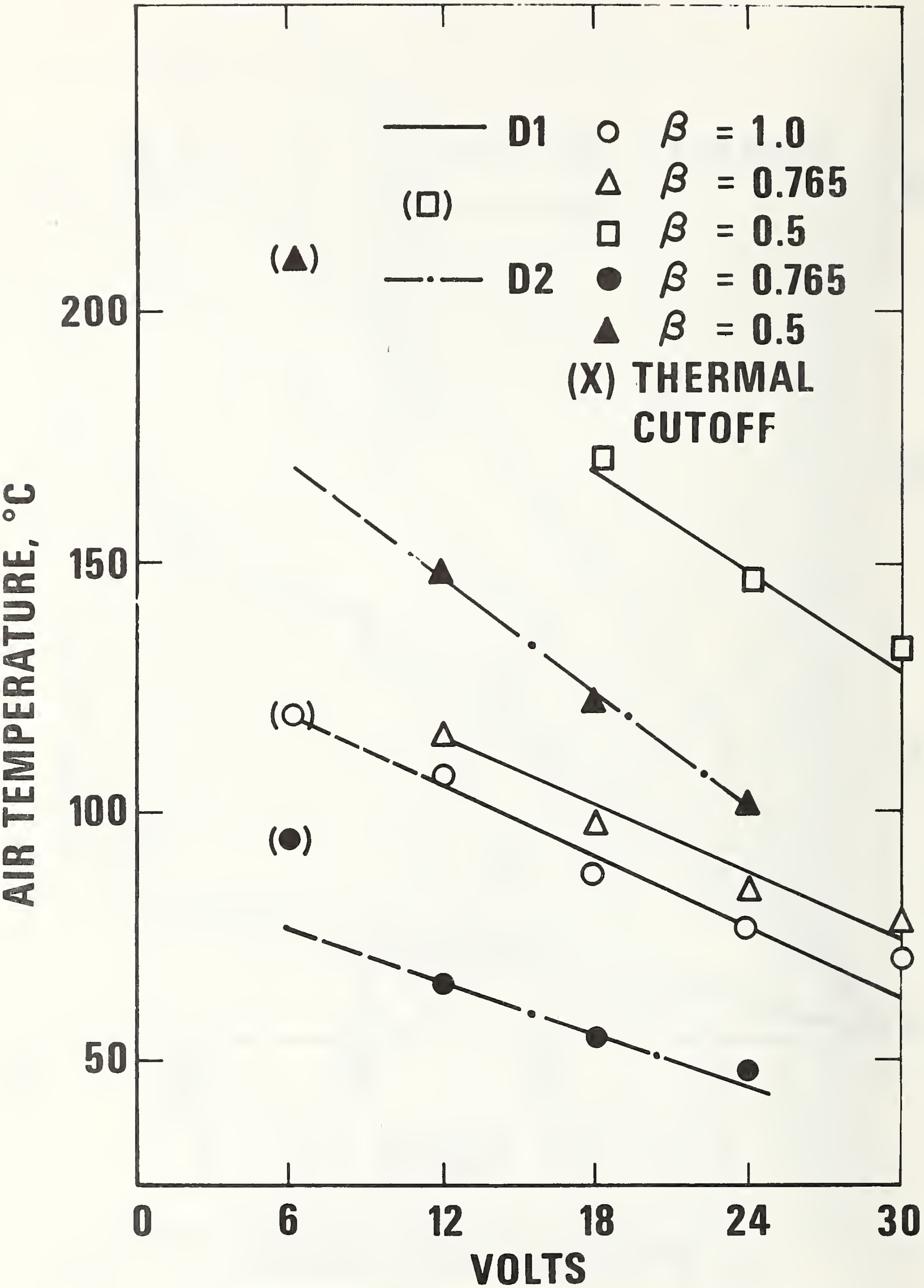

Figure 4. Air temperatures at various motor voltages for different flow restrictions, β.

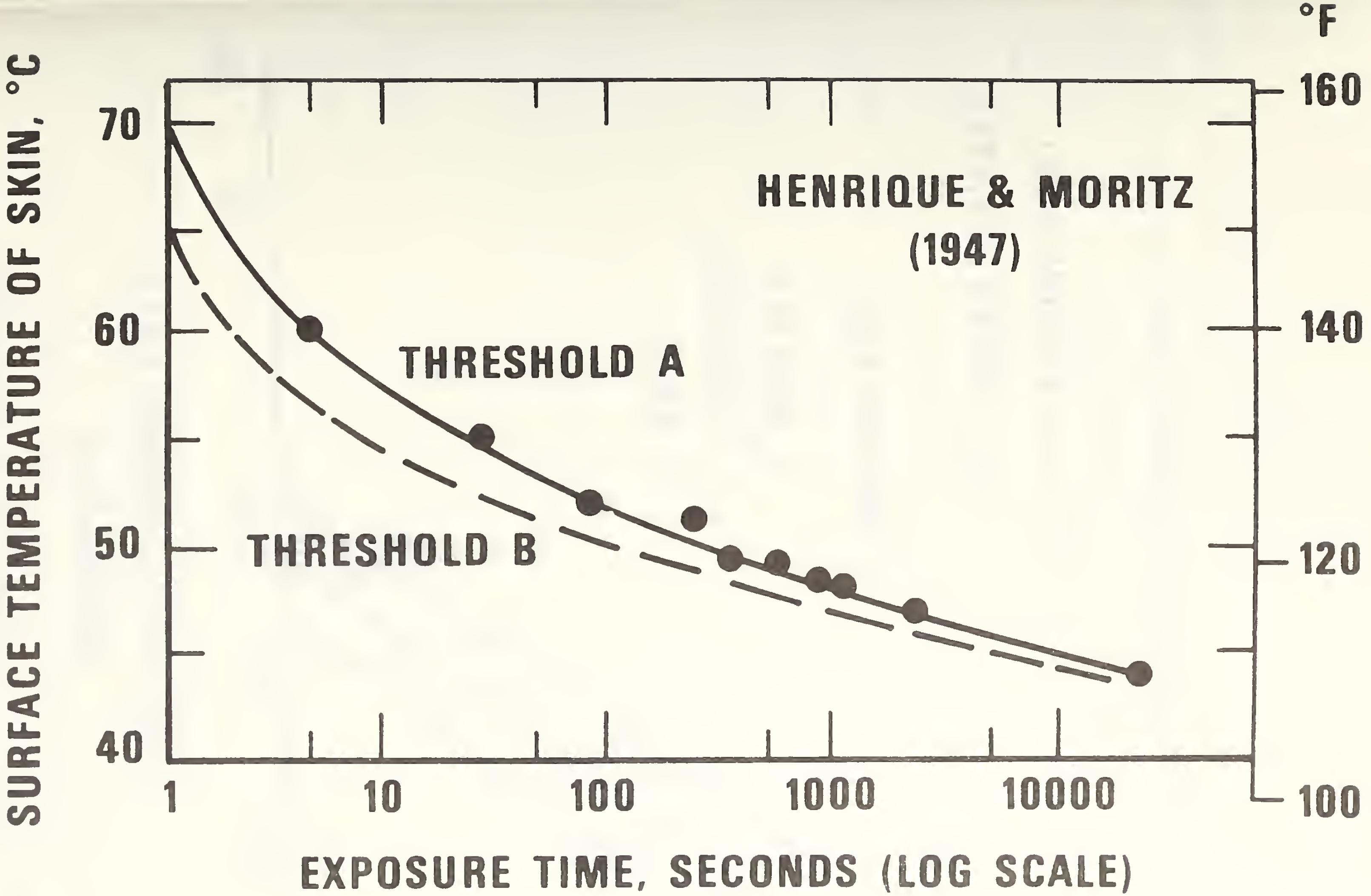

Figure 5. Temperature-time relation in burns. Threshold A is the lowest temperature-time required for irreversible burn and threshold B is the highest permissible temperature-time for thermal safety 6/.

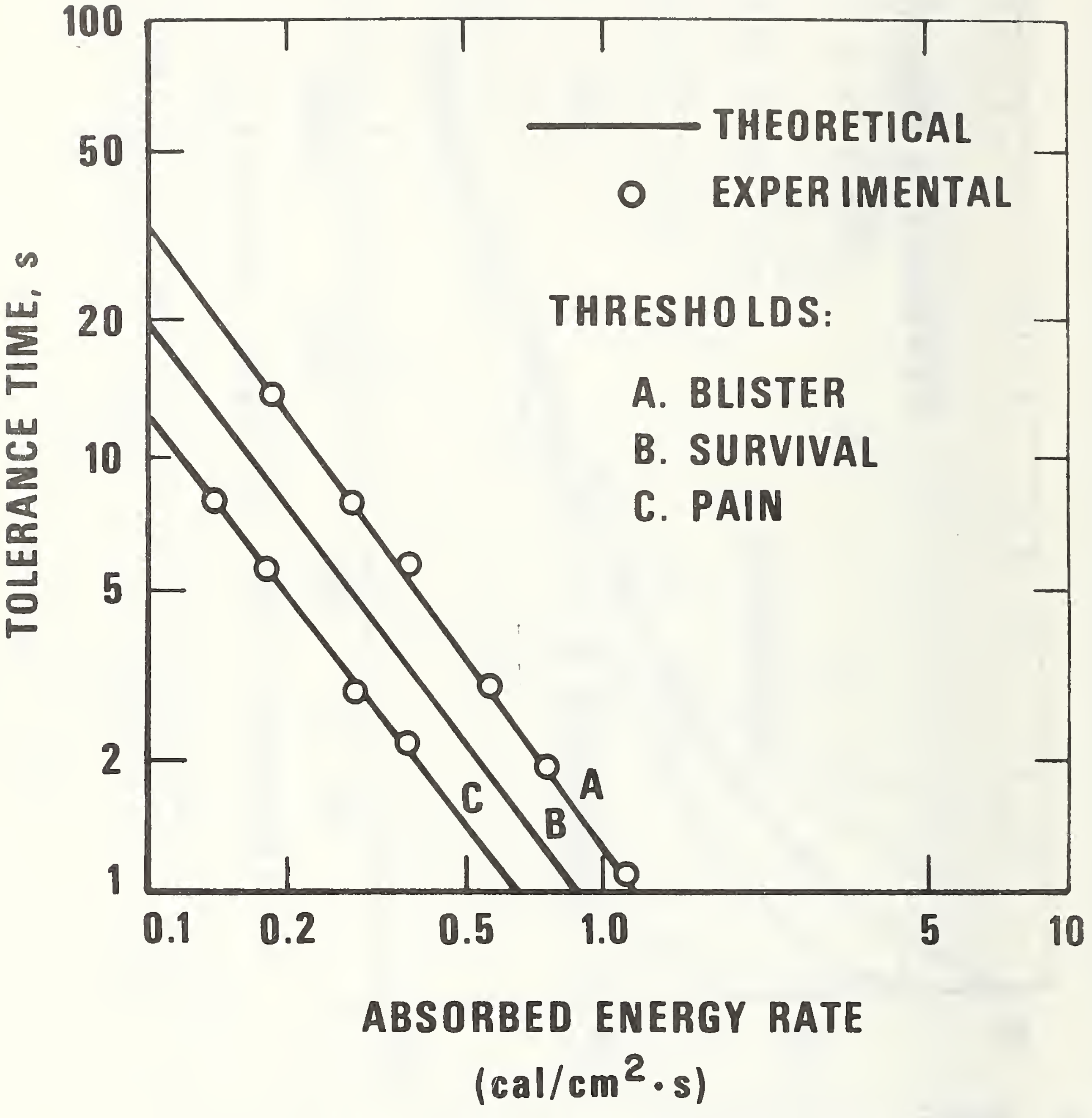

Figure 6. Human skin tolerance time to absorb thermal energy 7/. (Log-log scale and 1 $cal/cm^2 \cdot S$ = 4.186 $watt/cm^2$.)

Appendix

Theory of Orifice Flow Meter

A fluid flows through a pipe with diameter, D, and an orifice with an opening diameter d, then the volume of the fluid flow, Q in m^3/s, will be

$$Q = v_A A = v_a a \qquad (1)$$

where v's are the velocity of fluid in m/s. A and a are the areas of the pipe and the orifice opening, respectively.

then $$v_A = v_a \frac{a}{A} \qquad (2)$$

From the law of energy conservation

$$1/2\ Mv^2 = Mgh \qquad (3)$$

where M = the mass of the fluid

g = gravitational acceleration

h = differential head of the fluid

thus $$v_a^2 - v_A^2 = 2g(h_a - h_A) \qquad (4)$$

so that $$v_a = \sqrt{2g(h_a - h_A)} \bullet 1/\sqrt{1-(a/A)^2} \qquad (5)$$

From the Bernoulli's theory:

$$p + 1/2\ \rho\ v^2 = \text{const.} \qquad (6)$$

where p = pressure

ρ = density

combining eqs. (4) and (6), and let $\gamma = g\rho$, it yields

$$h_a - h_A = (p_A - p_a)/\gamma \qquad (7)$$

Putting eq. (7) into (5), the velocity of the fluid in terms of pressure and diameters of the orifice opening and the pipe becomes

$$v_a = \sqrt{2g\ (P_A - P_a)/\gamma} \quad \bullet \quad 1/\sqrt{1 - \beta^4} \tag{8}$$

where $\beta = d/D = \sqrt{a/A}$

and the flow rate,

$$Q = a\sqrt{2g\ (P_A - P_a)/\gamma} \quad \cdot \quad 1/\sqrt{1 - \beta^4} \tag{9}$$

The actual flow rate through a head meter is practically always less than the indicated theoretical flow rate, hence a correction factor, the so-called "discharge coefficient," C, must be introduced which may be defined as:

$$C = \frac{\text{actual rate of flow}}{\text{theoretical rate of flow}} \tag{10}$$

so that

$$Q_{actual} = a\left(C/\sqrt{1 - \beta^4}\right)\cdot\sqrt{2g\ (P_A - P_a)/\gamma} \tag{11}$$

The factor $C/\sqrt{1 - \beta^4}$ is replaced by K, the flow coefficient, which has been tabluated in the ASME report 8/. It should be noted that the units used in the report are those fph units, To avoid a lengthy conversion, the computation in this report was first in fph units; after the corrections, SI units were employed.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The hand held dryer/styler is an efficient and popular small appliance, but a high injury trend associated with such products has been reported. Hazards commonly associated with the product are electrical, mechanical and thermal. In this study, the relation between these hazards and human tolerance limits were analyzed and experiments to investigate the probable cause and potential of such hazards were conducted. Randomly selected samples of the product were subjected to relevant safety performance tests of the UL Standard 859. In addition, air flow rate, heat flux and surface temperature were measured on several samples in order to determine their thermal hazard potential. Based on the results of these investigations, corrective measures are suggested.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Air flow rate; electrical, mechanical and thermal hazards; hair dryer/stylers; heat flux; safety; temperature; technical analysis.

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