A Novel Approach to Measuring Fluid Flow in Incontinence Pads

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1. INTRODUCTION

Urinary incontinence (UI) is a problem, particularly among the chronically ill, which is caused by several different factors. Regardless of whether it is due to ageing or to dysfunction of the nervous or motor system, people dealing with this disease live in permanent discomfort. In addition to the physical discomfort, UI has important psychological and social implications and because it affects a large number of patients in hospitals and long term care facilities, various treatments have been proposed in an attempt to deal with it [1].

The most common strategy to reduce the impact of UI is to use absorbent products, such as diapers and underpads. Most of these products have a structure similar to that illustrated in Figure 1. The top layer or coverstock, which is in contact with the individual's skin, is made from a soft, flexible and smooth material that allows rapid transmission of liquid [2]. One or more absorbent layers are inserted under the coverstock together with a waterproof bottom layer, and the composite structure is then stitched or fused together.

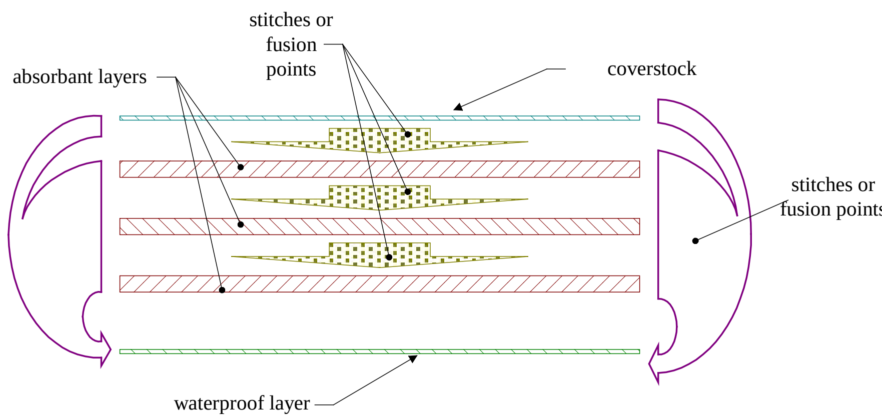

Figure 1 – Typical structure of an incontinence pad.

From the user's point of view, the ideal pad has to absorb and disperse fluid effectively, regardless of the volume, flow rate and frequency of wetting [3]. Over the years, a wide variety of test methods have been developed to measure key performance parameters such as wicking rate (or diffusivity), absorption rate, absorbent capacity, wettability and permeability. Techniques used to date to measure the moving wet/dry boundary during a horizontal wicking test have relied on monitoring changes in electrical resistance or capacitance, or observing the dispersion of a dyed liquid with a digital camera.

Since neither of these methods have proven very accurate or reliable, one of the objectives of the present study was to assess the feasibility of using infrared thermography (IRT) to measure horizontal wicking or

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dispersive characteristics of incontinence pads. A second objective was to determine wheter IRT could also be used to monitor the rate of moisture loss from reusable incontinence pads through evaporation during the drying cycle.

The remainder of the paper briefly introduces the concept of IRT and describes the equipment, methods and results obtained using this novel technique to measure the wicking and drying characteristics of four commercial incontinence products available on the Canadian market.

2. INFRARED THERMOGRAPHY

The principle of IRT analysis is simple. (1) The thermal radiation emitted by a body is a function of its temperature and surface emissivity. (2) An infrared camera [4] can be used to convert this thermal radiation into visible light. (3) For a uniform, isotropic structure, the image received by the camera is uniform. (4) If there is an imperfection or a change at or beneath the surface of a structure, then the thermal response will no longer be uniform.

In this way, the analyst can interpret the image transmitted by the camera in terms of potential flaws or changes in the structure. Two approaches can be considered: passive thermography or active thermography. In passive thermography, the sample is at an average temperature, which is different from the ambient or room temperature. Specific applications for this technique are in the fields of electronics, where passive thermography is used to cross-check weldings on printed boards. In the glass and metal industries, passive thermography is employed to record variations in temperature profiles and so optimize production rates. This type of analysis is also used in numerous other applications.

In this study passive thermography was considered the most appropriate approach since wet and dry surfaces can provide the radiometer (camera) with different thermal responses.

3. EXPERIMENTS AND RESULTS

3.1 Horizontal wicking or rate of dispersion

In order to simulate the conditions associated with a patient wearing a diaper, it is necessary to evaluate the behaviour of the pads in a confined and enclosed area. This ensures that there is no evaporation, and that all the fluid remains distributed inside the pad. Because different forms of UI are related to two different types of urine flow, the dispersion tests included two injections procedures: 1) a single injection and 2) drop by drop injections.

3.1.1 Parameter of interest

The parameter of interest is the rate of area dispersion represented by the *diffusivity* of the sample, *dA/dt* (cm^2/min). Because of their different injection procedures, the parameters associated with the single and drop by drop flows were named *transient diffusivity* and *steady state diffusivity* respectively.

3.1.2 Experimental apparatus

The main experimental apparatus involved was a Cincinnati IRC-160 infrared camera (Figure 2). A hermetically sealed casing was used to enclose the specimen during the tests. It contained a probe which permitted the injection of fluid without opening the casing. The casing, shown in Figure 3, involved an upper surface that had to be transparent to thermal radiation in the wavelenght range concerned with the experiments. The enclosure was customized to be adapted to all specimens to be investigated.

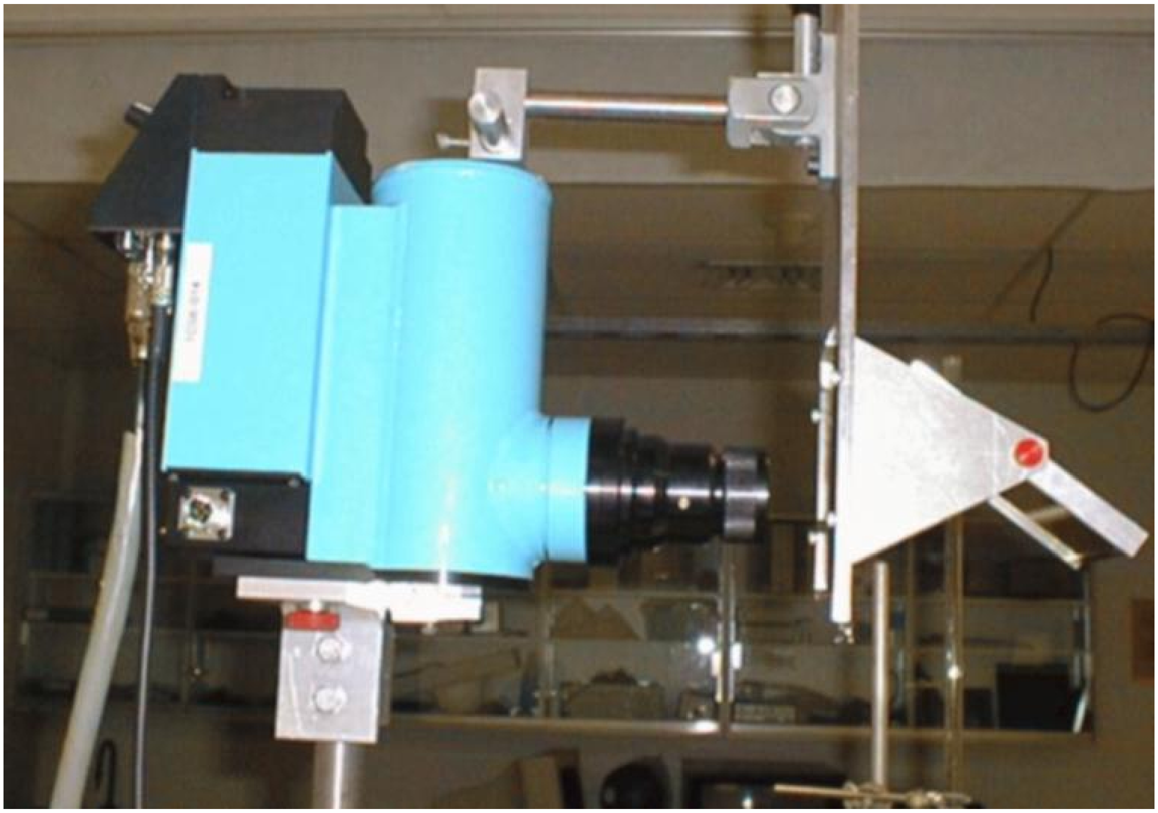

Figure 2 – Cincinnati IRC-160 infrared camera

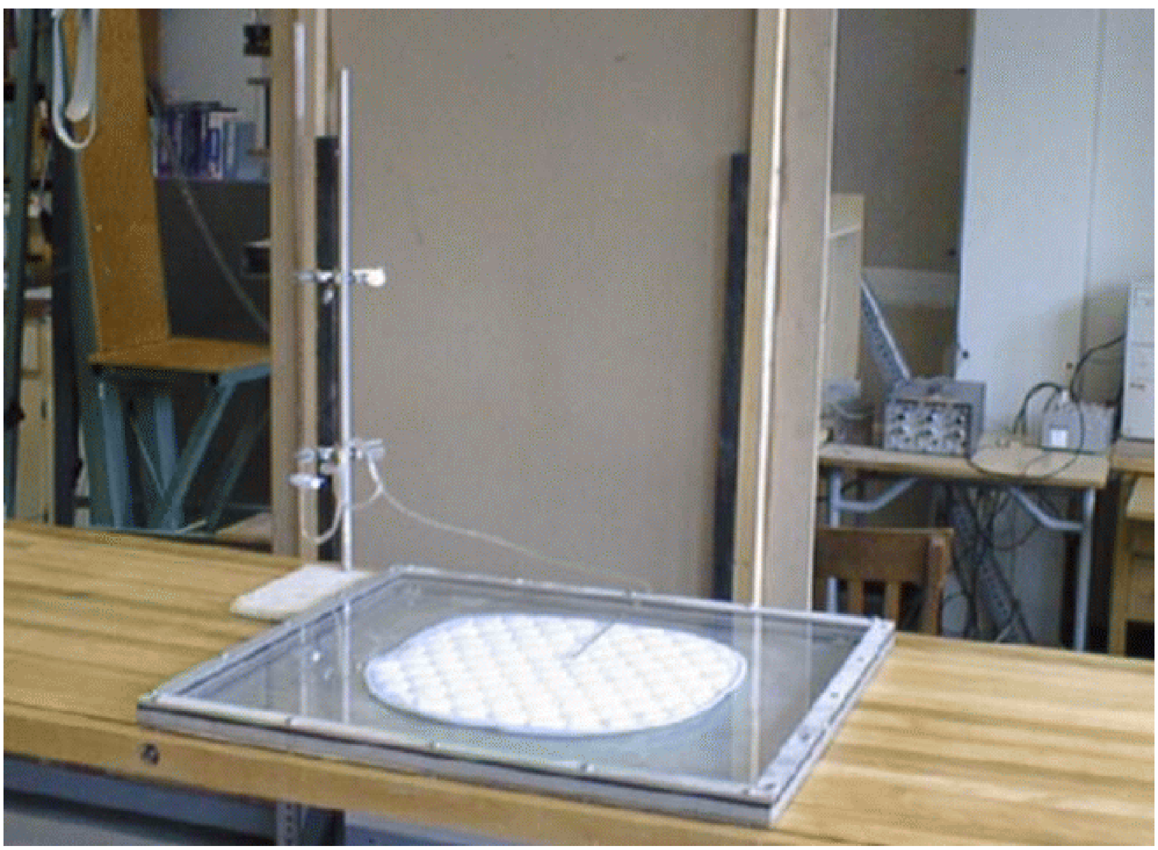

Figure 3 – Hermetically sealed enclosure

3.1.3 Measurement techniques

The method relied on the ability of the infrared thermography equipment to distinguish between the surface emissivity and temperature of wet and dry regions of a pad. Acquisition of several infrared images provided a measurement of diffusivity by observing the propagation of a wet zone across the surface of each specimen. For both single injection and drop by drop injections, the data obtained from the IRC-160 camera underwent a series of treatments to reveal the relevant information. Briefly, successive images were subtracted one from another and the number of pixels within the contour defined by the subtraction was converted into square centimetres, cm^2. The technique is schematically illustrated in Figure 4.

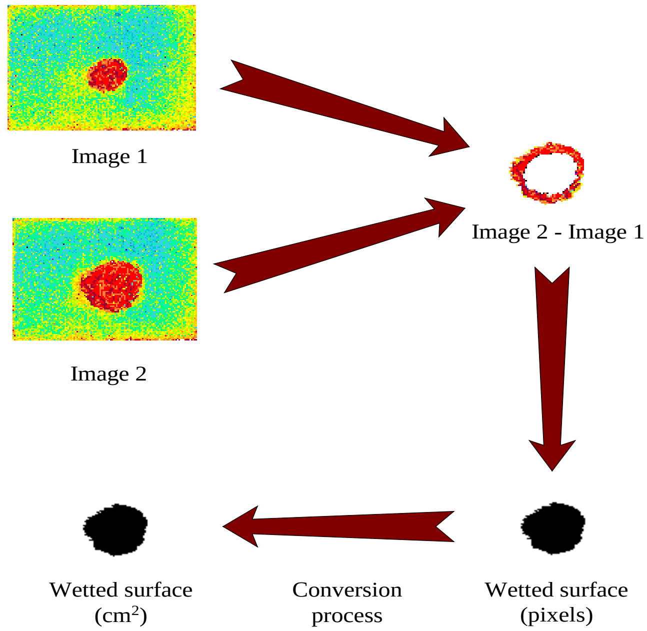

Figure 4 – Processing used for IRT images converting

3.1.4 Results

3.1.4.1 Single injection

An initial volume of 50ml of water was injected at the beginning of the experiment. The wetted area was observed at specified intervals over a period of 30 minutes. Variations in the size of the wet region are depicted as a function of time in Figure 5. The increase in the area of the wet region is represented by a linear regression for the first two minutes of the test, and by a second order regression for the remaining time. The diffusivity parameter represents the first derivative of these curves. For the linear regression, it corresponds to the graphic *transient diffusivity*, $(dA/dt)_{trans}$. The experimental values of this parameter were obtained from Newton's forward differentiation method [5]. These values are represented by crossmarks and their mean value may easily be calculated over the range.

An inspection of the graphic results shows that $(dA/dt)_{trans}$ is high at the beginning of the test, and it decreases towards zero by the end of the test. This behaviour is due to the movement of water in the absorbent layers. Initially, the free liquid moves under its own weight, but when it reaches the bottom of the pad, it has no choice but to disperse horizontally away from the injection point. Later, restrained liquid is dispersed by several simultaneous transport mechanisms[6]; capillarity, humidity gradients, etc. The nature of the results does not permit us to determine the relative importance of each of these mechanisms. However, it is obvious that the two forms of liquid flow do exist at the beginning of the experiment, and that as the area of the wet region increases, the importance of the free liquid flow decreases. While the first portion of $(dA/dt)_{trans}$ curve may be represented by a straight line, the remaining curve is more accurately represented by a second order relationship. The results for one of the Absorb-Plus underpads are presented in Figure 5 and the characteristics of the other products are to be found in Table 1 for the two tests involving the most discrepencies.

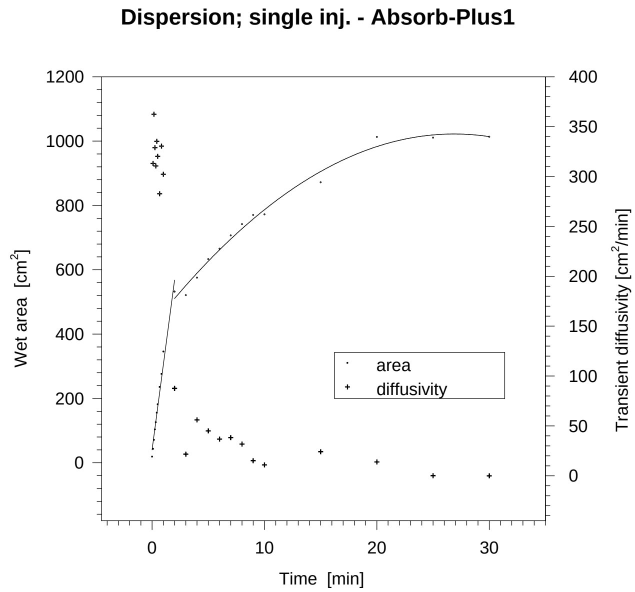

Figure 5 – Variations of the wet region as a function of time for single injection tests

Table 1 – Results: transient diffusivity

SAMPLES		***A_{max}, wet area*** [cm^2]	***$(dA/dt)_{trans}$*** [cm^2/min]
Absorb-Plus	1st test	1013	297,3
	2nd test	972	286,6
Protection Plus	1st test	681	305,8
	2nd test	644	244,8
Formedica	1st test	859	348,6
	2nd test	855	334,7
Sancella	1st test	671	198,6
	2nd test	433	158,2

3.1.4.2 Drop by drop injections

Repeated amounts of liquid (5ml) were injected every 5 minutes over a period of 30 minutes and the evolution of the wetted surface was observed by IRT over this time period. Again, the increasing area of the wetted region was observed and reported as a function of time (Figure 6). The evolution of the wetted surface is expressed by a first order relationship with the slope corresponding to the graphic *steady state diffusivity* parameter, $(dA/dt)_{S.S}$. The experimental values of $(dA/dt)_{S.S}$ obtained from Newton's method are represented by crossmarks.

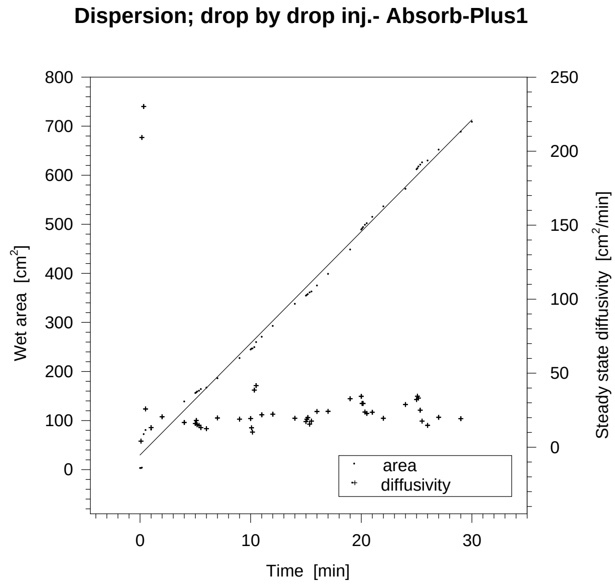

Figure 6 – Variations of the wet region as a function of time for drop by drop injections tests

The liquid transport mechanisms discussed in Section 3.1.4.1 were also observed during the drop by drop injection experiment. However, the injection procedure did not permit the stabilisation of a fixed wet region but contributed to a constantly increasing area. Once again, the results presented in Figure 6 are related to one of the Absorb-Plus underpads. The characteristics of the other products are to be found in Table 2.

Table 2 – Results: steady state diffusivity

SAMPLES		$A_{wet\ area}$ ***final*** [cm^2]	***(dA/dt)$_{S.S}$*** [cm^2/min]
Absorb-Plus	1st test	709	22,1
	2nd test	795	24,2
Protection Plus	1st test	580	21,0
	2nd test	493	15,2
Formedica	1st test	608	18,8
	2nd test	n.d.	n.d.
Sancella	1st test	550	33,5
	2nd test	506	26,8

3.2 Rate of moisture loss through evaporation

The time required to dry a reusable incontinence pad is a preponderant factor in institutions that use a large quantity of such products. In today's climate of budgetary restraint in the health care sector there is an obvious incentive to develop underpads that dry quickly with a minimum amount of energy consumption. As a result, the Energy Research Group at Laval University was asked to formulate and implement a technique to measure the amount of water evaporated in a given period of time.

3.2.1 Parameter of interest

To provide a comparative basis for different underpads, it was decided to perform evaporation testing for all samples in still air. It was assumed that the total amount of liquid to be evaporated would cross the wetted surface at the top of the sample during the test. The idea here was to link evaporation rates with the fibre and textile structure of the underpad. The evaporation mass flow rate per unit area, $\dot{m}''_{evap}$ (g/cm^{2}s) was defined as the characteristic parameter of interest.

3.2.2 Experimental apparatus

As evaporation occurs, so the surface temperature decreases and allows the thermography camera to visualise the surfaces where evaporation takes place. In this experiment, the variations in mass were recorded on a digital balance. The thermography equipment used during these tests is described in section 3.1.2. A Sartorius BP 6100 Digital Balance and National Instruments Labview Data processing software installed on a Pentium© PC were also used.

3.2.3 Measurement techniques

The mass of liquid evaporated, m_{evap}, at a given time, t, was calculated by subtracting the total sample mass, m_t, at time t from the initial mass, m_0, at t_0. m_{evap} was normalised for all samples. The thermography images are treated as described in Section 3.1.3.

3.2.4 Results

The results are presented in terms of the evaporated mass per unit area in (g/cm^2) versus time in minutes (min) in Figure 7 for one of the *Absorb-Plus* pads, which was exposed to a single injection of 50g of water. At a glance, it can be seen that the mass flux is nearly steady; that is, the slope is nearly constant. This indicates that diffusion according to Fick's law [7], is the dominant parameter and that the anisotropy of the structure plays a role in the slope of the graph but not in its shape. A constant slope according to Fick's law is observed for steady state conditions. However, within the first few minutes of testing, the effective evaporation area was still growing which produced evaporation fluxes that were lower than average. This is explained by the horizontal dispersion of fluid that takes place simultaneously with evaporation in the transient period. It can also be seen that there is a slight increase in the evaporative flux with time. This additional effect is due to the structure of the hydrophobic top layer where evaporation takes place.

Table 3 presents the total mass evaporated per unit area over four hours, and the overall evaporation flux for four different products. The experimental values of $\dot{m}''_{evap}$ where obtained from Newton's forward differentiation method. Results presented in this section give an idea of the ability of one material to evaporate fluids per *unit area* in still air. However, these results have to be combined with those for wicking rates in order to yield meaningful information about the total amount of water that can be removed from a sample while evaporating in still air.

4. CONCLUSION

The primary objective of the research study to develop a novel approach for measuring certain characteristics of incontinence underpads was realised. In this paper, infrared thermography was used successfully to monitor the wicking diffusivity and rate of moisture loss through evaporation of four commercially available products: *Absorb-Plus*, *Protection Plus*, *Formedica* and *Sancella*.

Overall, the two methods described herein will improve the quality of life of those who may suffer from UI by facilitating the development of a new generation of products offering improved performance. The methods permit the R&D engineer to compare a product under development with existing products and therefore modify the design appropriately. In addition, these techniques could be applied to the evaluation of any textile structure for which wicking, dispersion and evaporation of fluid are critical performance parameters.

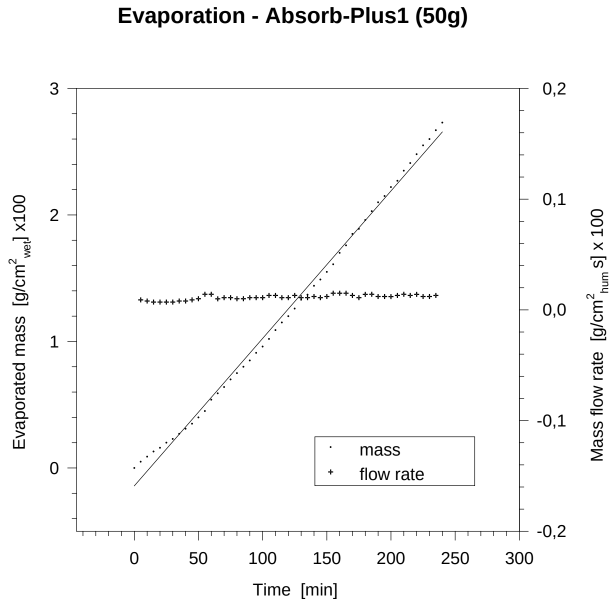

Figure 7 – Variations in mass of a specimen for the evaporation tests

Table 3 – Results: evaporation

SAMPLES		m''_{evap} [g/cm^2]x10^{-2}	$\dot{m}''_{évap}$ [g/cm^{2}s] x10^{-4}
Absorb-Plus	1st test	2,73	1,14
	2nd test	2,80	1,17
Protection Plus	1st test	2,10	0,87
	2nd test	2,26	0,94
Formedica	1st test	2,45	1,01
	2nd test	2,70	1,11
Sancella	1st test	1,56	0,63
	2nd test	1,54	0,64

5. REFERENCES

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SOMMAIRE

L'incontinence urinaire (IU) est une émission involontaire d'urine qui peut résulter de différentes causes (paralysies partielles ou totales, problèmes de motricité, etc.). Le traitement le plus commun de l'IU est l'utilisation de produits absorbants. Cet article porte sur l'élaboration d'une nouvelle approche expérimentale basée sur la thermographie infrarouge pour caractériser certains paramètres des produits absorbants: le débit d'évaporation massique et la diffusivité. Les méthodologies développées ont été appliquées à quatre types de piqués absorbants*; Absorb-Plus, Formedica, Protection Plus* et *Sancella*.

Des résultats expérimentaux typiques montrent que le produit Absorb-Plus a un débit d'évaporation de 1,14x10-4 g/cm^{2}s, une diffusivité transitoire de 297 cm^2/min, une diffusivité en régime permanent de 22,1 cm^2/min.

Les deux tests développés dans le cadre de ce projet permettront d'éventuellement améliorer la vie des gens atteints d'incontinence urinaire en facilitant le développement de nouveaux produits. L'approche présentée ici s'applique aux produits pour l'incontinence. Cependant, elle peut également être utilisée dans le développement de tout autre produit pour lequel les paramètres énoncés doivent être connus.