Transfer Rate of Moisture from Bath Towel to Human Skin During Hyper & Microgravity Conditions

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Abstract

The cleaning process in space involves the usage of bath towel. The bath towel would function in zero gravity in space. It would transfer moisture to the human skin. This is the process that astronauts go through. We are interested upon the rate of transfer of moisture from the bath towel to the human skin during microgravity condition as this would aid in the process of producing a more effective bath towel to be used by astronauts. We had performed several parabolic flight cycles and results were obtained during hyper and microgravity conditions which gave us an opportunity to make comparison. Comparisons with 1G data were also made.

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Introduction

The team performed several parabolic flights during the concourse of 2 days over the airspace of Nagoya in order to collect data in hyper and micro gravity conditions. During the first day, data from 10 parabolic cycles were collected. During the second day, data from 9 parabolic cycles were collected.

The parabolic flights were performed using a Gulfstream Aircraft owned by Diamond Air Services (DAS). Collaboration between the National Space Agency of Malaysia (ANGKASA), Japanese Aerospace Exploration Agency (JAXA), and Universiti Kuala Lumpur enable the team to perform the parabolic experiments. Each parabolic flight gave 20 seconds of microgravity condition which is an ample time to record the results of moisture transfer.

Schramek in his paper stated that the absorption of water for a particular towel depends upon yarn material, yarn type and fabric construction [1]. For our experiments, we constrict ourselves to only 2 types of towel, thus designating the towel as the control parameter. The corresponding section details out the characteristic of the towels of our experiments.

We also had positioned our towels at horizontal and vertical positions. This gave us a wide breadth of observation on whether orientation plays a role or not in propagating the transfer rate of moisture. We ran through several papers which were particularly fond of using the horizontal setup. This gave us precedents of data (horizontal in nature and in 1G) which we could compare upon. Masoodi in his experiment used the horizontal setup to investigate the absorption rate of certain towels [2]. Ours in different as we were also actuating the experiment in hyper and microgravity conditions in contrast to 1G as performed by Masoodi. Nevertheless we will take his experiment as a platform for comparison

Governing Equation

We are dealing with the transfer of fluid from one body to another. We measured the rate of transfer via the transfer of mass in a particular time and area. We designated the area as $1cm^2$ as this is the "best" area captured by our sensors. The sensors captured the readings every one second.

Washburn Equation, which is shown below, governs our experiments.

$$L^2 = (\gamma d t) / (4 \mu)$$

L is the distance a liquid has travelled in time t , γ is the surface tension of the liquid, d is the pore diameter, and μ is the liquid viscosity. This can be re-written in terms of the mass (M) of fluid absorbed, the permeability, K , and driving pressure ΔP.

$$M = \rho\, T\, W\, \sqrt{(2K\, \Delta P / \mu)}\, \sqrt{t}$$

T and W are the thickness and width of the porous material and ρ is the liquid density, and the relationship of fluid absorbed vs. time is a square root relationship for a one-dimensional linear flow [3]. Our experiments measured the values of M. All other parameters of the equation are controlled parameters. We have a simplistic view and postulated that a change in gravitational value would affect the driving pressure ΔP, thus altering the value of M. Pressure as equated by (mass * gravitational acceleration)/area and (mass * gravitational acceleration * height) comprises of the gravitational component [4][5].

We however did not consider radial absorption as it is not within our scope to measure how fast the moisture spread at a particular area. We concentrated upon our objective of measuring transfer between 2 separated bodies.

Experiment Apparatus

The primary structures are 2 plates at horizontal and vertical positions. Figure 1 shows the setup.

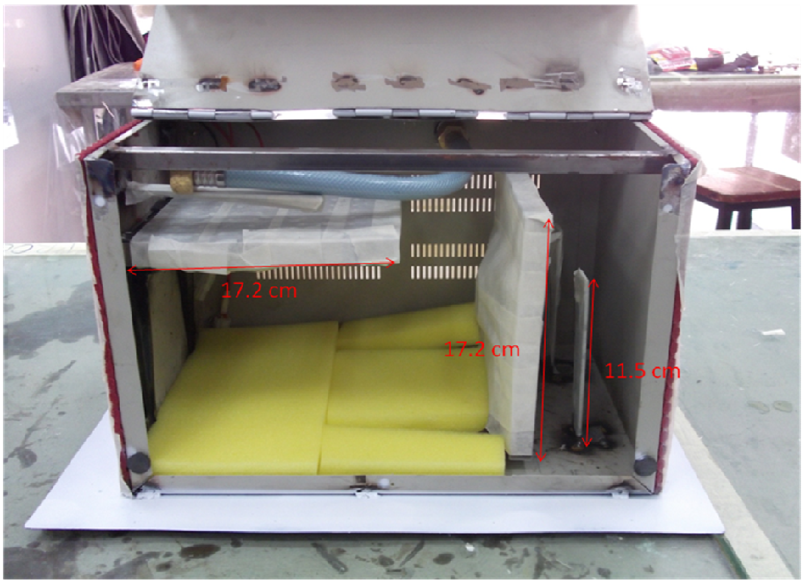

Figure 1. Horizontal & Vertical Plate

Both plates are infested with holes which bleeds fluid when a switch is actuated. Towels are attached to both plates and an artificial skin is attached to each towel. The sensors are clad throughout the artificial skin. The skin is shown in Figure 2.

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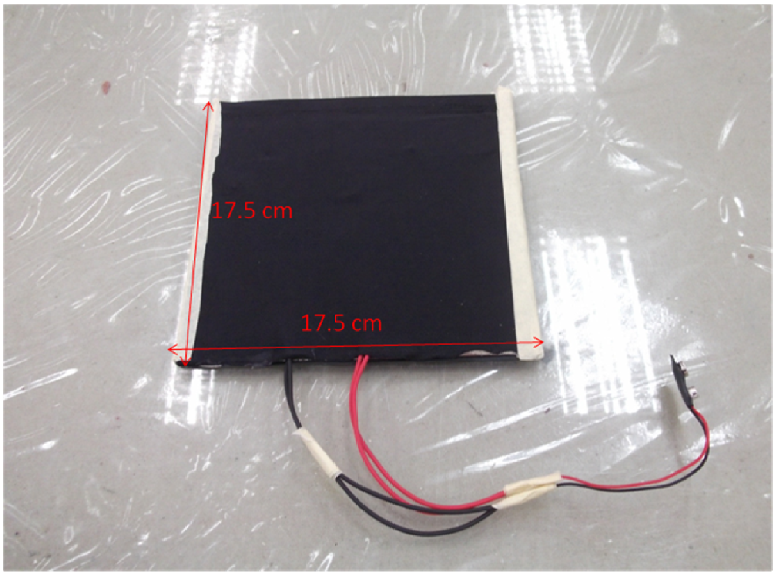

Figure 2. The Artificial Skin

The skin that we used mimics the skin of a human to a certain degree. It is a spandex made of polyurethane which exhibits almost human like characteristics [6]. Table 1 gives details of the skin.

Table 1

Mechanical / Physical Properties	**Artificial Human Skin (Polyurethane)**
Tensile Strength (LW)	100,000 psi
Flexural Strength (LW)	100,000 psi
Interlaminar Shear	7,500 psi
Bearing Strength (LW)	45,000 psi
Water Absorption	0.3 % Max
Density	0.07 lb/in^3
Notched Izod Impact (LW)	78 ft-lb/inch

Our towels are of 2 types. They differed in several categories. Table 2 shows the details.

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Table 2

	Towel Type 1	Towel Type 2
Hp	4.9	5.7
Density, Yarn/cm (Weft)	20	17
Density, Yarn/cm (Warp)	28	24
Porosity (ratio)	0.56	0.38

Experiment Procedures

The team was given 2 days of parabolic flights. On the first day, 10 readings were recorded where each reading was recorded each parabolic cycle and towel type 1 was used. On the second day, 9 readings were recorded where each reading was recorded each parabolic cycle and towel type 2 was used. Table 3 gives details on the experiments.

Table 3

	Towel Type 1	Towel Type 2
Day	First	Second
Horizontal Position	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} parabolic cycle	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} parabolic cycle
Vertical Position	6^{th}, 7^{th}, 8^{th}, 9^{th}, and 10^{th} parabolic cycle	6^{th}, 7^{th}, 8^{th}, and 9^{th} parabolic cycle
Anomalies	Vertical Position (8^{th} and 9^{th} parabolic cycles)	Horizontal Position (4^{th} and 5^{th} parabolic cycles)
Microgravity Reading	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th}, and 10^{th} parabolic cycle	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, and 9^{th} parabolic cycle
Hypergravity Reading	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th}, and 10^{th} parabolic cycle	1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, and 9^{th} parabolic cycle

Results & Discussions

As shown in Table 3, there are anomalies in the readings at certain cycles. We would show in this section the results which are acceptable and comment upon them. The anomalies are shown in another section with comments attached. We have produced several graphs of the acceptable results which are shown in this section.

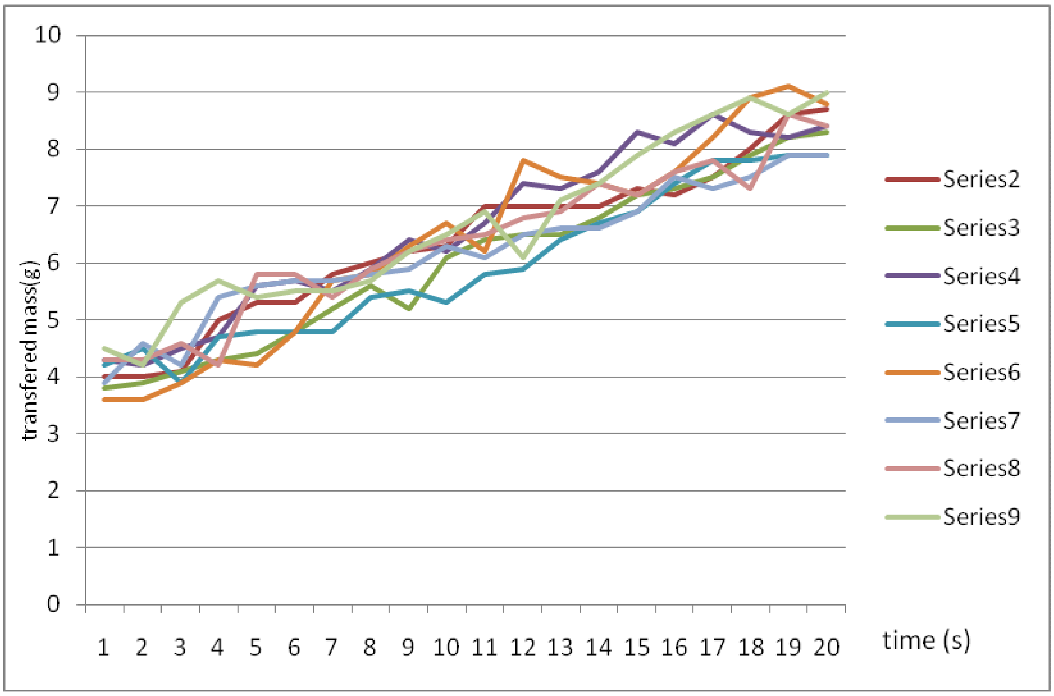

Figure 3. Data during Microgravity Condition – Towel Type 1

In Figure 3, there are series of graphs which indicate the transferred liquid during the period of microgravity. Below is shown the correlation between series of graph and the parabolic cycles.

i. Series 2 : 1st Parabolic Cycle (Horizontal Position)
ii. Series 3 : 2nd Parabolic Cycle (Horizontal Position)
iii. Series 4 : 3rd Parabolic Cycle (Horizontal Position)
iv. Series 5 : 4th Parabolic Cycle (Horizontal Position)
v. Series 6 : 5th Parabolic Cycle (Horizontal Position)
vi. Series 7 : 6th Parabolic Cycle (Vertical Position)
vii. Series 8 : 7th Parabolic Cycle (Vertical Position)
viii. Series 9 : 10th Parabolic Cycle (Vertical Position)

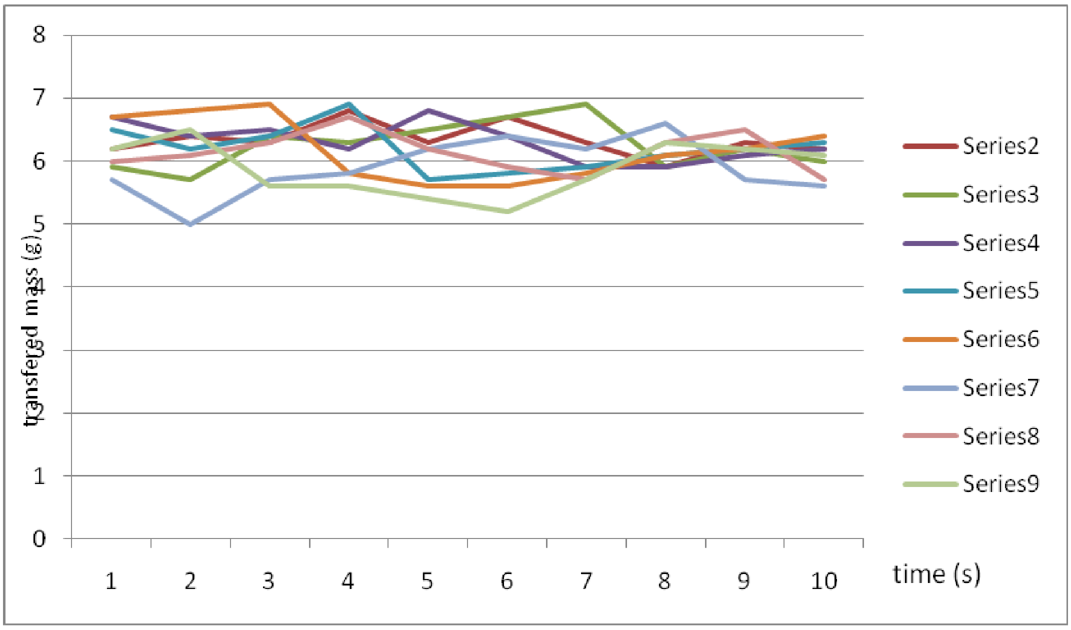

Figure 4. Data during Hypergravity Condition – Towel Type 1

In Figure 4, there are series of graphs which indicate the transferred liquid during the period of hypergravity. We only captured the readings for 10 seconds during the hypergravity period. Below is shown the correlation between series of graph and the parabolic cycles.

i. Series 2 : 1st Parabolic Cycle (Horizontal Position)
ii. Series 3 : 2nd Parabolic Cycle (Horizontal Position)
iii. Series 4 : 3rd Parabolic Cycle (Horizontal Position)
iv. Series 5 : 4th Parabolic Cycle (Horizontal Position)
v. Series 6 : 5th Parabolic Cycle (Horizontal Position)
vi. Series 7 : 6th Parabolic Cycle (Vertical Position)
vii. Series 8 : 7th Parabolic Cycle (Vertical Position)
viii. Series 9 : 10th Parabolic Cycle (Vertical Position)

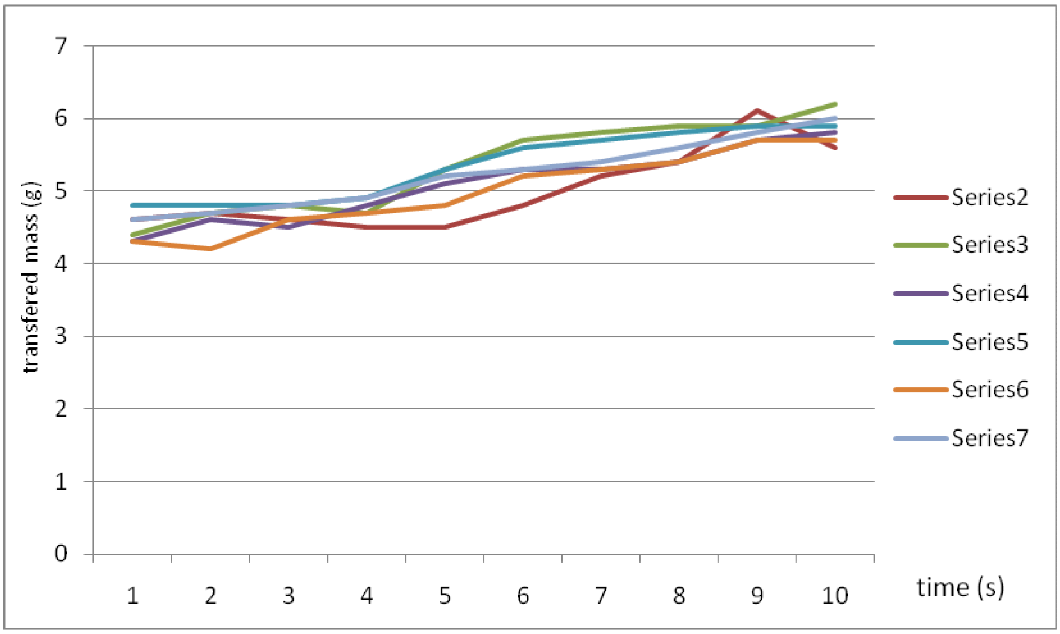

Figure 5. Data during 1G Condition – Towel Type 1

In Figure 5, there are series of graphs which indicate the transferred liquid during the period of 1G. We only captured the readings for 10 seconds during the 1G period which were actuated on the ground. Below is shown the information of the series of graph.

i. Series 2 : Horizontal Position
ii. Series 3 : Horizontal Position
iii. Series 4 : Horizontal Position
iv. Series 5 : Vertical Position
v. Series 6 : Vertical Position
vi. Series 7 : Vertical Position

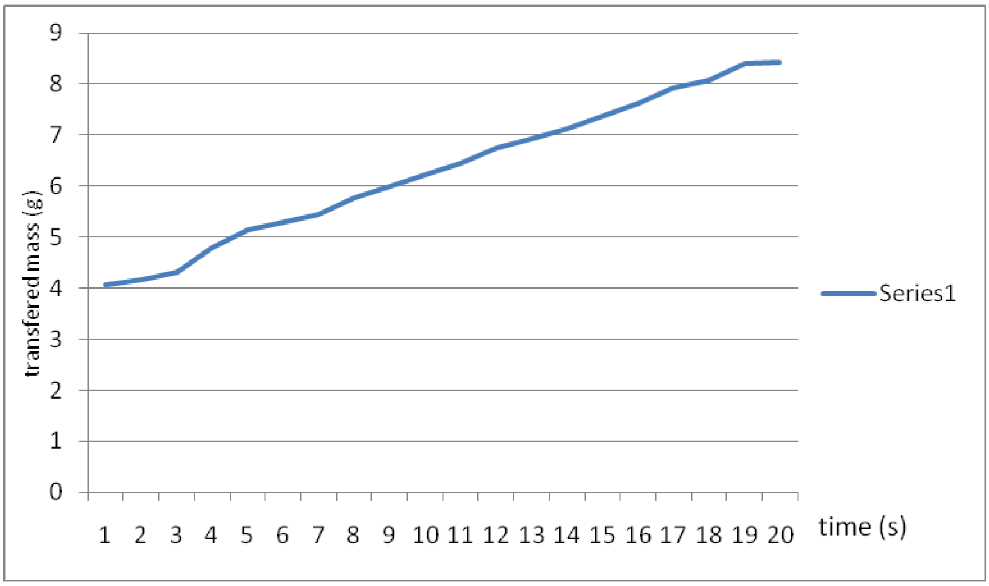

Figure 6. Averaged Data during Microgravity Condition – Towel Type 1

We took all of the graphs in Figure 3 and concatenated and averaged them and the result is shown in Figure 6. We will use Figure 6 for comparison with conditions of hypergravity and 1G.

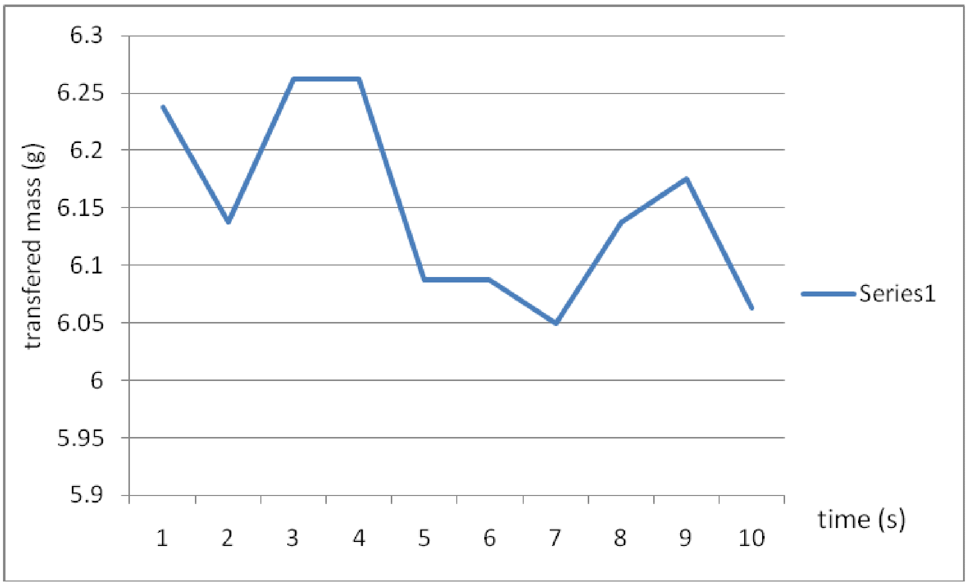

Figure 7. Averaged Data during Hypergravity Condition – Towel Type 1

We took all of the graphs in Figure 4 and concatenated and averaged them and the result is shown in Figure 7. We will use Figure 7 for comparison with conditions of microgravity and 1G.

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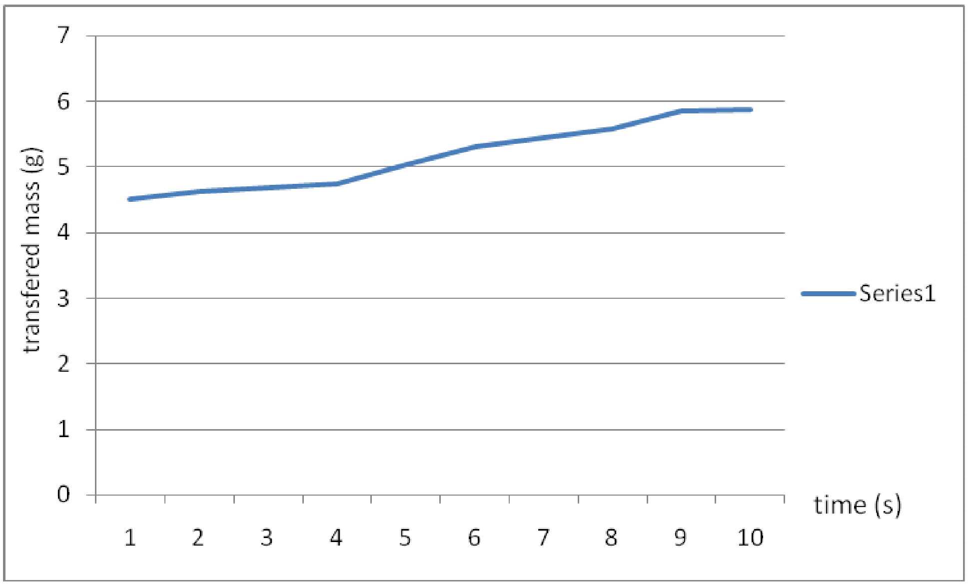

Figure 8. Averaged Data during 1G Condition – Towel Type 1

We took all of the graphs in Figure 5 and concatenated and averaged them and the result is shown in Figure 8. We will use Figure 8 for comparison with conditions of microgravity and hypergravity.

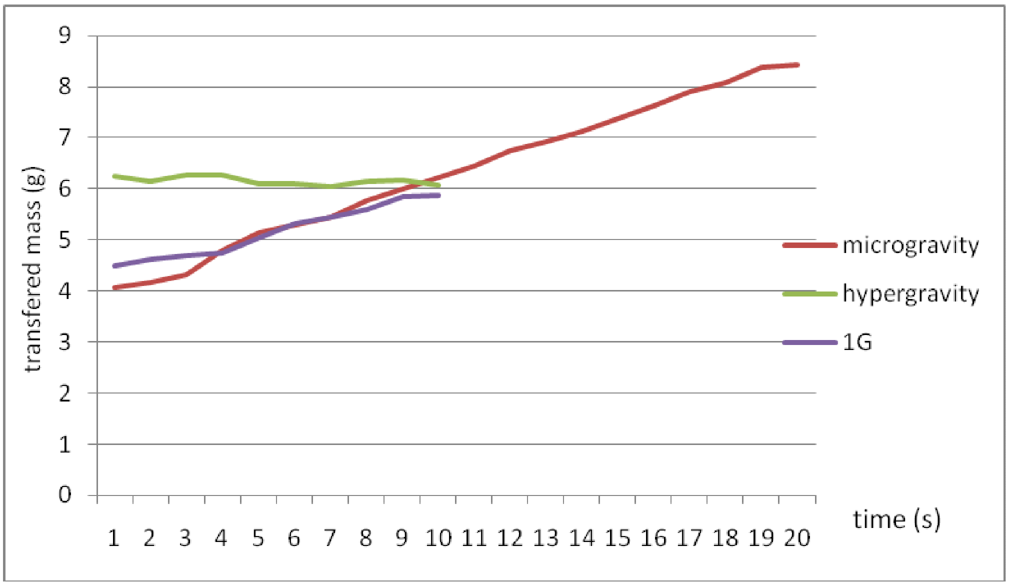

Figure 9. Comparison of Transferred Mass during Microgravity, Hypergravity, and 1G Conditions – Towel Type 1

We took the graphs from Figures 6, 7, and 8 and produced a comparison as shown in Figure 9. During the comparison, we noted that there are distinct variations (even though small) upon the transfer rate of moisture. We are satisfied with this and reasoned out that our postulation earlier that gravity affects the driving pressure is not farfetched. We intend to parlay more reasons of these occurrences in another paper as this is not within the scope of this paper.

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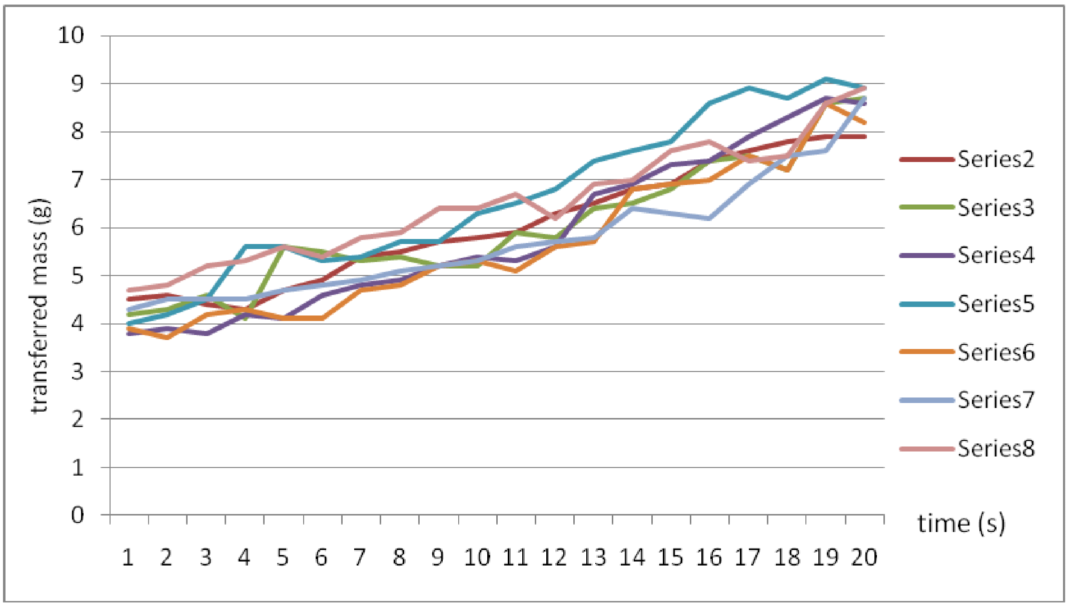

Figure 10. Data during Microgravity Condition – Towel Type 2

In Figure 10, there are series of graphs which indicate the transferred liquid during the period of microgravity. Below is shown the correlation between series of graph and the parabolic cycles.

i. Series 2 : 1st Parabolic Cycle (Horizontal Position)
ii. Series 3 : 2nd Parabolic Cycle (Horizontal Position)
iii. Series 4 : 3rd Parabolic Cycle (Horizontal Position)
iv. Series 5 : 6th Parabolic Cycle (Vertical Position)
v. Series 6 : 7th Parabolic Cycle (Vertical Position)
vi. Series 7 : 8th Parabolic Cycle (Vertical Position)
vii. Series 8 : 9th Parabolic Cycle (Vertical Position)

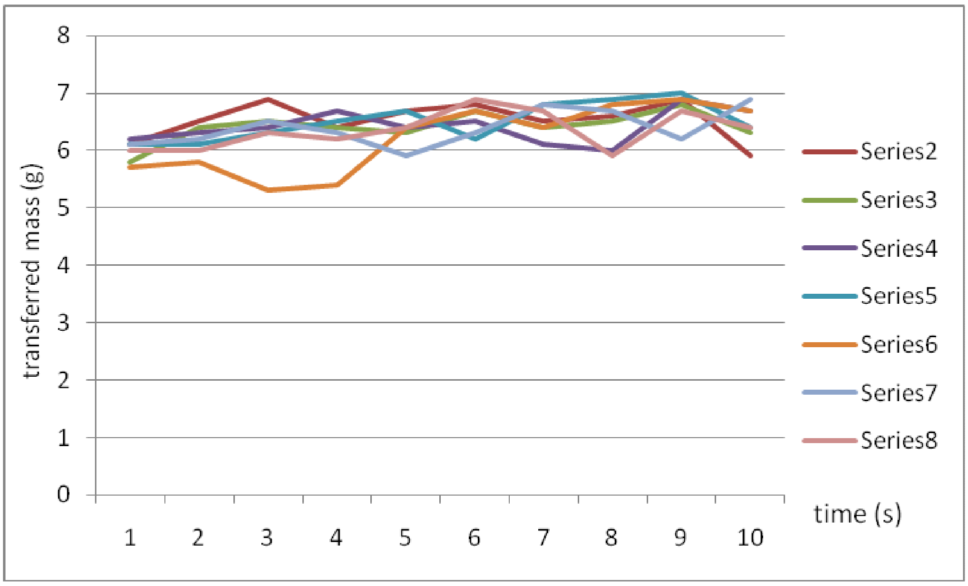

Figure 11. Data during Hypergravity Condition – Towel Type 2

In Figure 11, there are series of graphs which indicate the transferred liquid during the period of hypergravity. We only captured the readings for 10 seconds during the hypergravity period. Below is shown the correlation between series of graph and the parabolic cycles.

i. Series 2 : 1st Parabolic Cycle (Horizontal Position)
ii. Series 3 : 2nd Parabolic Cycle (Horizontal Position)
iii. Series 4 : 3rd Parabolic Cycle (Horizontal Position)
iv. Series 5 : 6th Parabolic Cycle (Vertical Position)
v. Series 6 : 7th Parabolic Cycle (Vertical Position)
vi. Series 7 : 8th Parabolic Cycle (Vertical Position)
vii. Series 8 : 9th Parabolic Cycle (Vertical Position)

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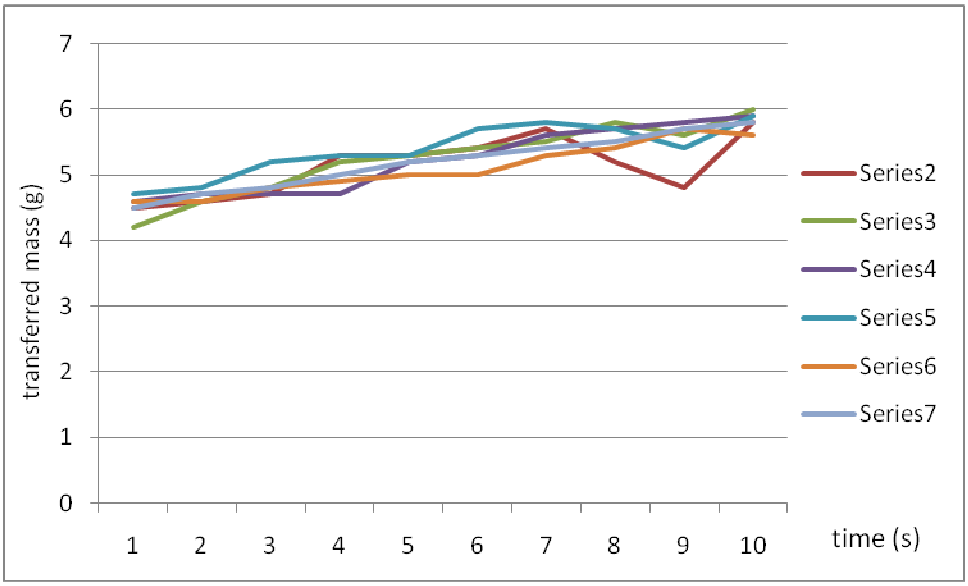

Figure 12. Data during 1G Condition – Towel Type 2

In Figure 12, there are series of graphs which indicate the transferred liquid during the period of 1G. We only captured the readings for 10 seconds during the 1G period which were actuated on the ground. Below is shown the information of the series of graph.

i. Series 2 : Horizontal Position
ii. Series 3 : Horizontal Position
iii. Series 4 : Horizontal Position
iv. Series 5 : Vertical Position
v. Series 6 : Vertical Position
vi. Series 7 : Vertical Position

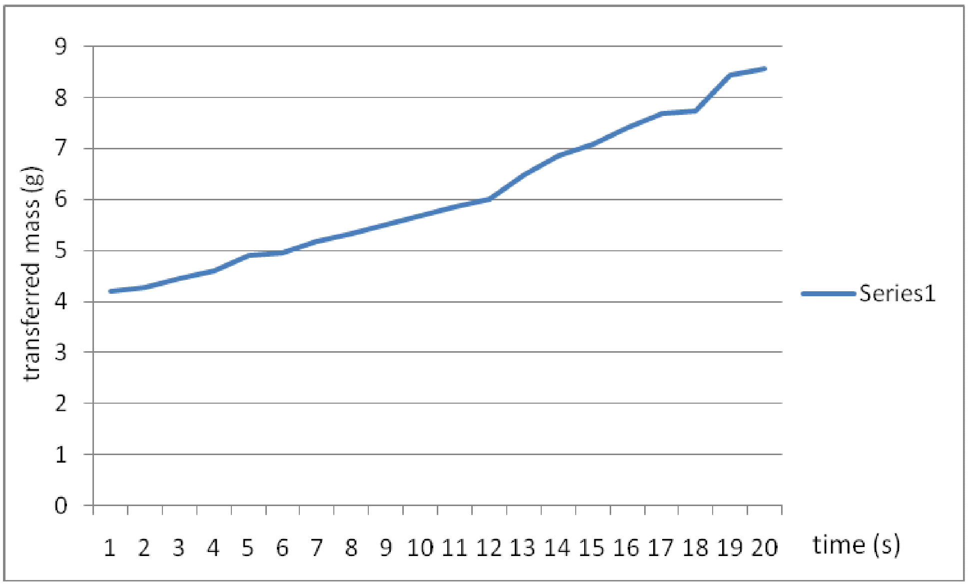

Figure 13. Averaged Data during Microgravity Condition – Towel Type 2

We took all of the graphs in Figure 10 and concatenated and averaged them and the result is shown in Figure 13. We will use Figure 13 for comparison with conditions of hypergravity and 1G.

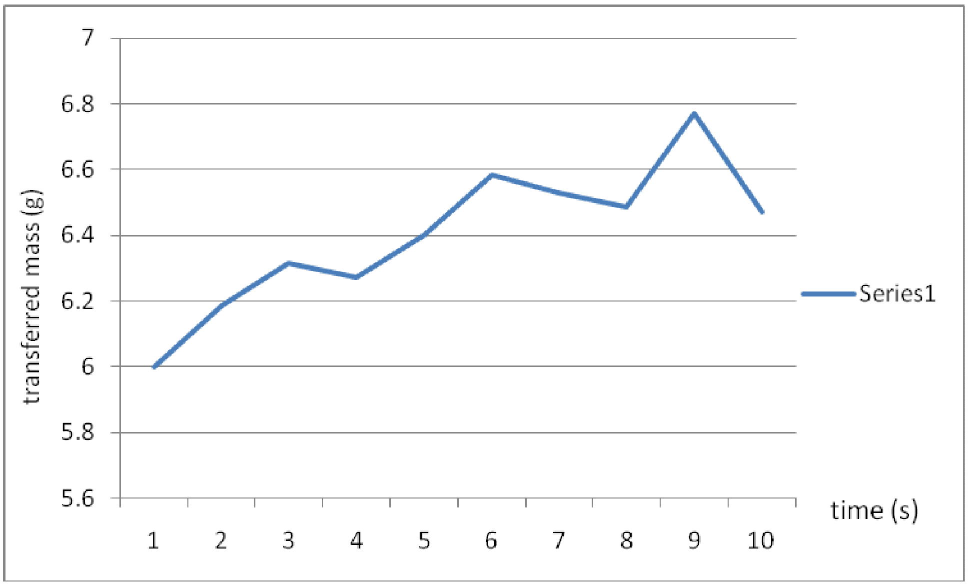

Figure 14. Averaged Data during Hypergravity Condition – Towel Type 2

We took all of the graphs in Figure 11 and concatenated and averaged them and the result is shown in Figure 14. We will use Figure 14 for comparison with conditions of microgravity and 1G.

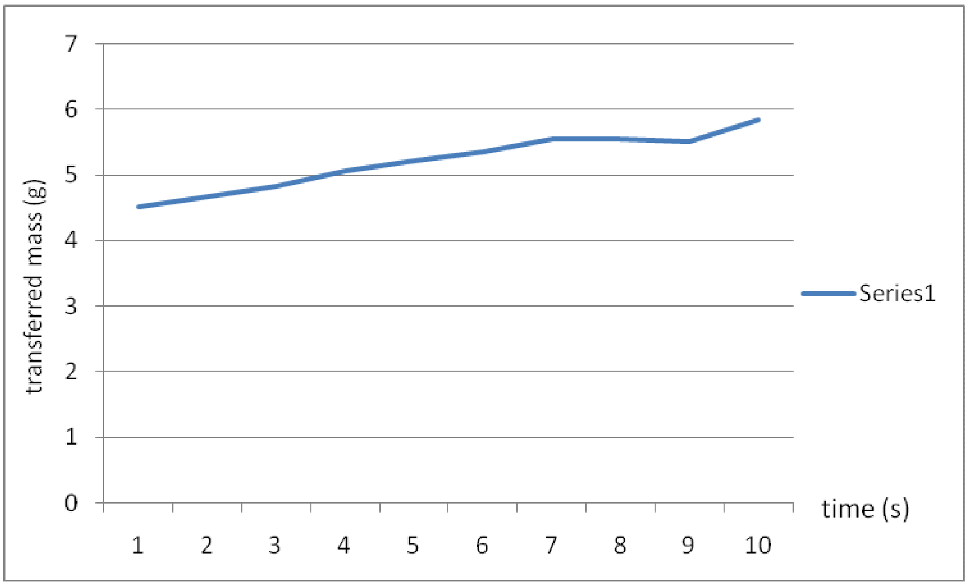

Figure 15. Averaged Data during 1G Condition – Towel Type 2

We took all of the graphs in Figure 12 and concatenated and averaged them and the result is shown in Figure 15. We will use Figure 15 for comparison with conditions of microgravity and hypergravity.

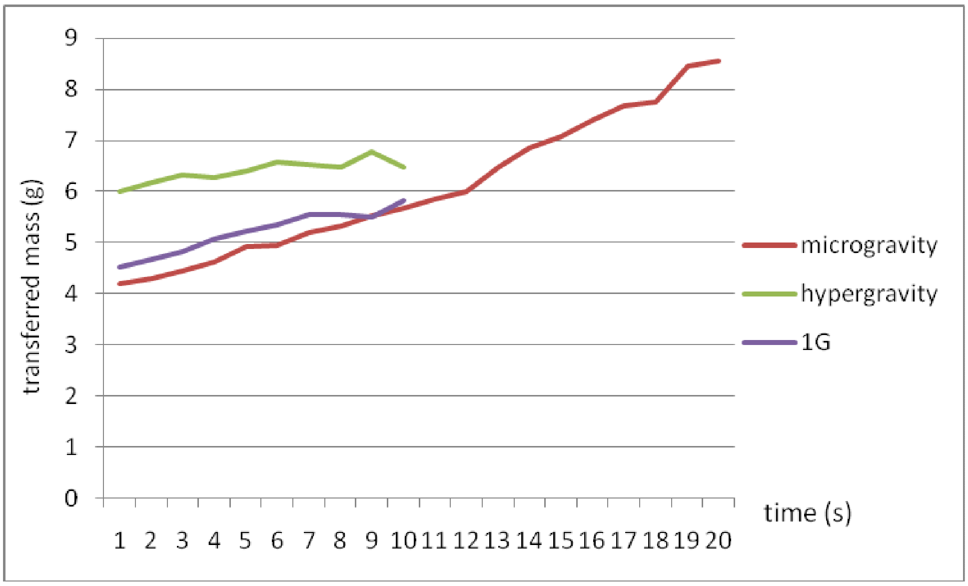

Figure 16. Comparison of Transferred Mass during Microgravity, Hypergravity, and 1G Conditions – Towel Type 2

We took the graphs from Figures 13, 14, and 15 and produced a comparison as shown in Figure 16. During the comparison, we noted that there are distinct variations (even though small) upon the transfer rate of moisture. We are satisfied with this and reasoned out that our postulation earlier that gravity affects the driving pressure is not farfetched. We also, as stated earlier, intend to parlay more reasons of these occurrences in another paper as this is not within the scope of this paper.

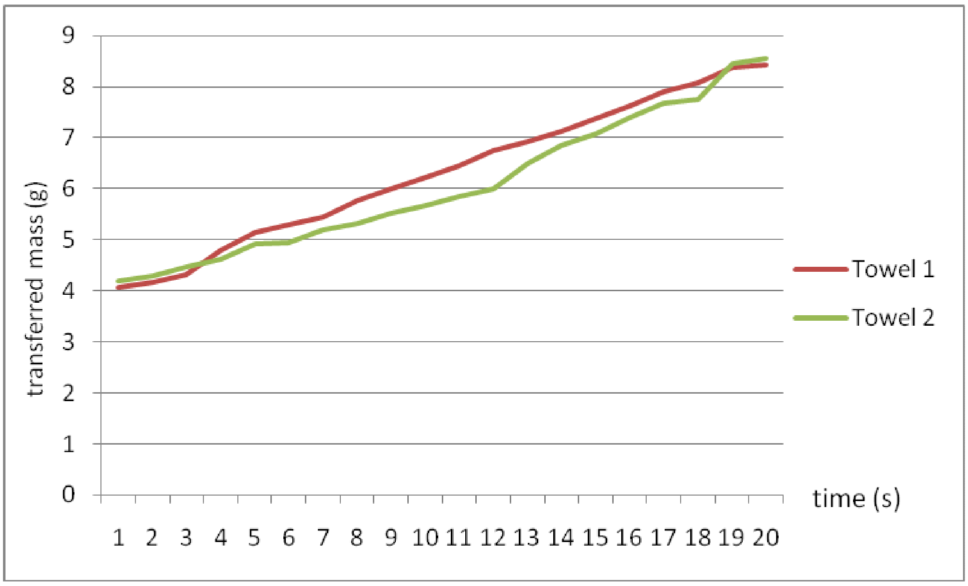

Figure 17. Comparison between Towel 1 and 2 – Microgravity Condition

We made a comparison between Towel 1 and 2 by comparing Figures 6 and 13 and the comparison is shown in Figure 17. During microgravity condition, it seems there's only a small difference of reading between Towel 1 and 2. These differences occurred due to the different nature of both towels as outlined in Table 2.

Figure 18. Comparison between Towel 1 and 2 – Hypergravity Condition

We also made another comparison between Towel 1 and 2 by comparing Figures 7 and 14 and this comparison is shown in Figure 18. During hypergravity condition, it seems there's only a small difference of reading between Towel 1 and 2. We concurred with our previous assessment which is these differences occurred due to the different nature of both towels as outlined in Table 2.

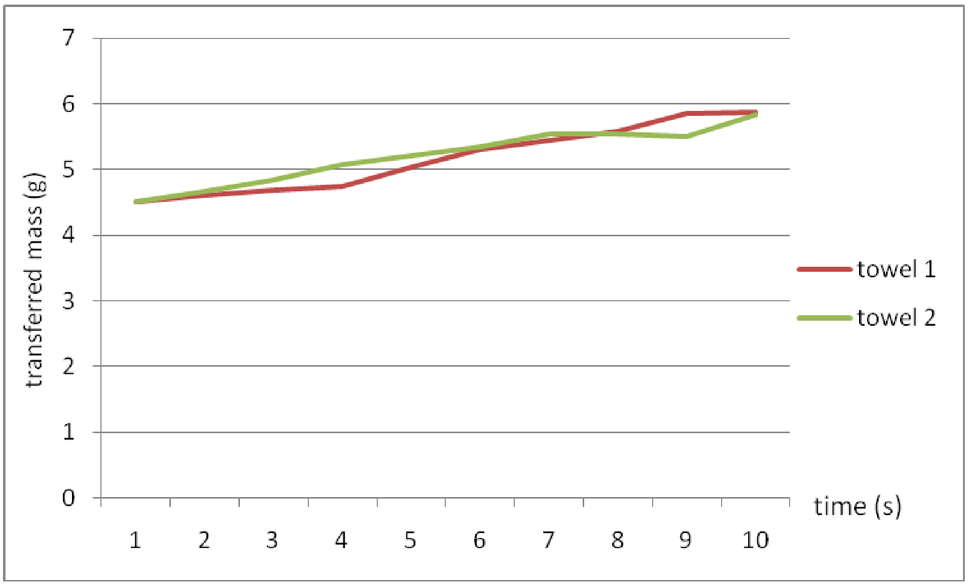

Figure 19. Comparison between Towel 1 and 2 – 1G Condition

We also made another comparison between Towel 1 and 2 by comparing Figures 8 and 15 and this comparison is shown in Figure 19. During 1G condition, it seems there's only a small difference of reading between Towel 1 and 2. We concurred with our previous assessment also which is these differences occurred due to the different nature of both towels as outlined in Table 2.

Anomalies

As mentioned in Table 3, there exist anomalies in our readings. For Towel Type 1, the anomalies occurred during parabolic cycles 8th and 9th (both vertical position measurement). The graphs of these anomalies are shown in Figure 20.

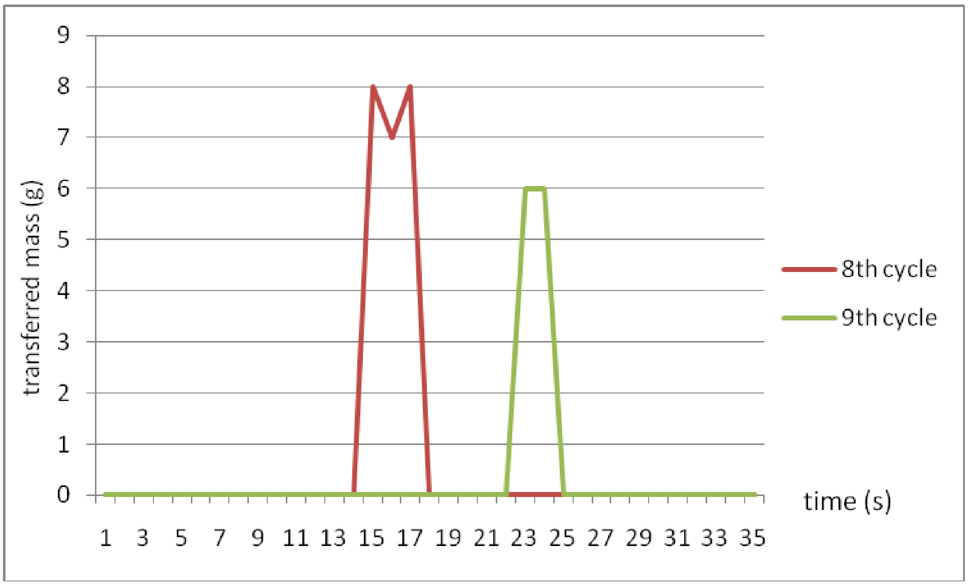

Figure 20. Anomalies for Towel Type 1

For Towel Type 2, the anomalies occurred during parabolic cycles 4th and 5th (both horizontal position measurement). The graphs of these anomalies are shown in Figure 21.

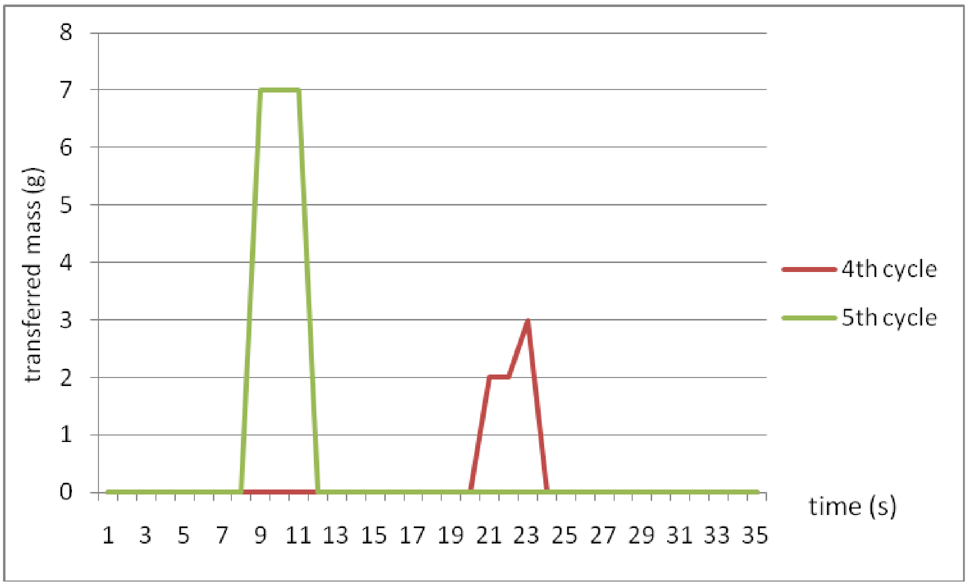

Figure 21. Anomalies for Towel Type 2

At this moment we could not offer a concrete reason on the existence of anomalies. We however suspected that a surge or under surge of current occurred in the circuitry that produced several snags as shown in the graphs. We intend to investigate further this phenomenon.

Conclusions

We have several conclusions. We noted that there exist differences in readings (of transfer rate of moisture) when comparison are made between 3 different conditions : microgravity, hypergravity, and 1G. The highest difference is around 2 grams for Towel Type 1. For Towel Type 2, the highest difference is also around 2 grams.

Both towels also exhibit differences in transfer rate of moisture. However these differences are minute where the highest difference is around 0.8 grams (from Figure 17). We had earlier indicated that the characteristics of the towel, as outlined in Table 2, played a role in producing these differences. We however cautioned that induced vibration during flights could also be a contributing factor. Other factors also come into play.

We nevertheless are satisfied with our results even though several anomalies existed. Overall these anomalies did not affect our entire results. We can perhaps make a judgement that, in relation to the mathematics that governed our experiment, gravitational values which instigate driving pressure play a role in determining the transfer rate of moisture from bath towel to human skin. We are cautious however as we did not dwell deeper onto the reason for such differences occurred during microgravity, hypergravity, and 1G conditions. We put forward several recommendations to put our worries at ease.

Recommendations

We would recommend the positioning of the towel at different angles. We in this experiment only tried 2 positions : horizontal and vertical. Using angles at 30 degrees or 45 degrees or 70 degrees would give perhaps different results.

We had used an artificial human skin and in the market there exist numerous materials that mimic human skin. We encourage future researchers to try materials different from ours. Perhaps different materials would give "optimum" results or "worse" results.

The parabolic flight that we undertook went from hypergravity to microgravity and when we peered upon the hypergravity and microgravity graphs, we observed a transition which is significant when condition changes from hypergravity to microgravity. We are interested in this transition period where values of transfer rate of moisture changed rapidly. Further research should look upon this.

Acknowledgement

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i. Diamond Air Services Japan
ii. Japanese Aerospace Exploration Agency
iii. National Space Agency of Malaysia
iv. Universiti Kuala Lumpur, Malaysia

With their support, the team managed to perform the experiments and collect relevant data.

References

[1] Schramek G, 2009. Konzepte zur kostenbewussten produktion von Frottierwaren. Melliand Textilberichte, 90(6): 236-237
[2] Masoodi 2010, Effect of Externally Applied Liquid Pressure on Wicking in Paper Wipes, Journal of Engineered Fibers and Fabrics, Volume 5, Issue 3
[3] Washburn, E.V.; The Dynamics of Capillary Flow; *Phys. Rev.* 1921, 17, 273.
[4] Clark, J. 1995, "The Encyclopedia of Physics", Andromeda Oxford, Oxfordshire.
[5] Chang, R. 1993, "Chemistry in Action", McGraw-Hill, LA.
[6] Shawna S, "Data Sheet Polyurethane Pultrusions Series 4000", Creative Pultrusions, 2005.