# *The Effect of the BIOflex® Magnetic Pad on the Flow Rate of 5% Aqueous Saline Solution*

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## INTRODUCTION

The overall purpose of this investigation was to determine whether or not the BIOflex® magnetic pad did influence the circulation of blood. Because of the many complicating factors associated with the use of blood itself, such as coagulation etc., it was decided to work with a very simple system. To that end a 5% NaCl solution in distilled water was selected. The behaviour of the saline solution was compared with distilled water itself. Fluid was drained from a reservoir through a capillary which could be exposed to or isolated from the BIOflex® pad. There was no effect on the flow rate of distilled water. A statistically significant effect was found, $P < 0.001$, on the flow of the saline solution which was enhanced when the capillary was exposed to the magnetic pad. Preliminary measurements were made of the streaming potential which also showed no effect of the presence of the pad on distilled water but did show a positive effect on the aqueous NaCl solution. The flow was also enhanced when the meniscus of the falling liquid level in the reservoir was exposed to the pad. This appears to connect the capillary results with surface tension effects. This connection is compatible with known relationship of surface tension to the double layer at a liquid solid interface.

## MATERIALS AND METHODS

Two sets of experiments were carried out. First, a flow meter was designed which measured the change in buoyant force on a float. The float was suspended from a proving ring fitted with Si strain gauges which responded to the apparent weight of the float. A high performance, low noise strain gauge amplifier was built which had a gain of 6000 and RMS noise of 6 millivolts at the output. This is equivalent to a sensitivity for the input signal of 1 microvolt before amplification. This combined with the gauge factor of 100 for the Si strain gauges means that the minimum detectable strain level in the proving ring was 0.01 microstrain. The float was then initially immersed to a pre-determined level in a reservoir. As liquid was drained from the reservoir the depth of immersion of the float decreased which increased its apparent weight. The reservoir was drained through a capillary tube which could be exposed to a BIOflex® pad or other external magnetic field. The output of the strain gauge bridge was recorded using a Data 6000 acquisition system with permanent storage on floppy discs. Flow rates were measured of distilled water and of 0.5% aqueous saline both with exposure to the BIOflex® pad and without exposure.

In order to check the results obtained with the method described above, a second completely independent set of experiments were carried out. The second method was to simply drain a reservoir through a capillary, with and without exposure to the BIOflex® pad, for fixed periods of time and weigh the collected liquid. The reservoir consisted of a plexiglass tube 5 cm in diameter and 30 cm long. This was filled to a height of 13 cm and was drained through a glass tube whose flow could be controlled by a stop cock. This valve was configured so that it always opened to a fixed “on” position. Following the stop cock was a vertical length of silastic brand medical grade tubing manufactured by Dow Corning of outer diameter 1.95 mm and inner diameter 1.47 mm. A digital, electronic timer with resolution of 0.1 second was used to determine the time of the flow. The collected fluid was weighed on a Sartorius Excellence Toploader digital, electronic balance with 1 milligram resolution. The largest source of error appears to have been the reproducibility of turning the flow on and off. The distilled water was boiled to drive off dissolved air and cooled to room temperature. The NaCl solution was made by dissolving 50 grams of NaCl in 1000 cc of preboiled and cooled distilled water. The initial height of the fluid column was 56 cm. Before actual data was taken, flow through the system was maintained for 1 minute to remove any air bubbles. The entire apparatus was cleaned with detergent and thoroughly flushed before commencing a set of runs either with distilled water or the NaCl solution. A plexiglass holder slot was used to support and position the BIOflex® pad so that when present it rested against the vertical plastic capillary without deforming it in any way.

A crude and preliminary streaming potential experiment was conducted by inserting a copper electrode into the reservoir and another at the exit of the capillary tube. Electric potential difference measurements were made using a Kiethly digital

voltmeter. Measurements were made on distilled water and 5% aqueous saline solution with and without the BIOflex® pad. This experiment should be done with Ag/AgCl or calomel electrodes and will be repeated. The appropriate size electrodes were unavailable in time and, therefore, this rough experiment was run. The trial was not repeated to average out noise so that only the gross features have any meaning here. In a further flow experiment, a BIOflex® pad was wrapped around the reservoir from which the liquid drained. The pad was positioned so that the meniscus of the falling liquid level passed across the pad. The flow was compared with that obtained without the presence of a BIOflex® pad.

**RESULTS**

The outcome of this first set of experiments indicated when a flexible capillary was exposed to the BIOflex® pad, the flow rate of a 0.5% saline solution was increased while no effect was seen using a glass capillary. Furthermore, no effect was seen in any case if distilled water alone was used. The flow rate was approximately 3 ml/second which produced a strain gauge output change of approximately 27 millivolts per second. Thus the change in electric output was approximately 9 millivolts per milliliter of flow. The results are shown in Table 1.

**Table 1**

| Trial | Strain Gauge Signal | |
|---|---|---|
| | Without Pad (mV/Sec) | With Pad (mV/Sec) |
| 1 | 25.738 | 28.450 |
| 2 | 25.775 | 28.694 |
| 3 | 26.975 | 26.963 |
| 4 | 28.981 | 28.919 |
| 5 | 26.863 | 28.075 |
| 6 | 25.994 | 26.463 |
| 7 | 26.313 | 28.381 |
| | | |
| Mean: | 26.663 | 27.992 |
| Standard Deviation: | 1.135 | 0.923 |
| Flow Rate m1/Sec: | 2.871 | 3.01 |

Volume/Run = 52.511 mL

Total Voltage Change Per Run = 487.7 mV

millivolts change per millimeter of flow = 9.29

T - test value; $t=2.324$ $P<0.1$

The T test applied to the above data indicates that the flow rate is enhanced by the presence of the BIOflex® pad as compared to the flow without the pad. However, only a modest P value is obtained. Furthermore, the results should be checked against distilled water which would act as a control. No effect should be seen with distilled water. Moreover, this experiment was plagued by electrical noise coming from the effects of moisture on the strain gauge circuitry which caused slow dc voltage drifts. Although the experiments were repeated often enough to average out a large part of the noise, there was still a possibility that these drifts could be confused with actual changes in flow rate. Therefore, it was decided to redesign the measurement of flow rate and repeat the measurements as described in the previous section. The second set of flow measurements produced very satisfactory results. The simple draining of a reservoir and weighing the collected fluid escapes almost all sources of noise. A total of 20 runs were made under each flow condition, i.e. distilled water or NaCl solution with and without the pad. The average flow rate was approximately 1 gram per second. The results are shown in Table 2 and plotted in Figure 1.

**TABLE 2.**
Average Weight of Collected Sample Grams
Distilled Water 20 Runs
With and Without BIOflex® Pad

| Time Sec. | With | Without | Diff. | Std. Dev. | t Value |
|---|---|---|---|---|---|
| 60 | 62.03 | 62.05 | -0.02 | 0.49 | 0.20 |
| 120 | 121.03 | 120.82 | 0.22 | 0.92 | 1.05 |
| 180 | 178.16 | 178.02 | 0.15 | 0.62 | 1.05 |

**TABLE 3.**
Average Weight of Collected Sample Grams
5% Aqueous NaCl 20 Runs
With and Without BIOflex® Pad

| Time Sec. | With | Without | Diff. | Std. Dev. | t Value |
|---|---|---|---|---|---|
| 60 | 62.15 | 61.66 | 0.49 | 0.51 | 4.26 |
| 120 | 121.58 | 120.73 | 0.85 | 0.48 | 8.03 |
| 180 | 178.96 | 177.79 | 1.17 | 0.68 | 7.71 |

The t values comparing the data with and without the BIOflex® pad were computed, as shown in Tables 2 and 3. They show, as expected, that with distilled water there is no statistical difference in flow rates whether or not the magnetic pad is present. However, there is a statistical difference in the flow rates of the aqueous saline solution with the pad and without the pad with $P<0.001$. When the meniscus of the liquid in the reservoir was exposed to the magnetic pad and the flow collected over a three minute period, an excess of 3.579 grams was measured in the presence of the pad. This experiment was done only once. This difference is three times as large as that observed when the pad was applied to the capillary! Although this experiment must be confirmed by repeated trials, it does indicate that the magnetic pad alters the surface tension forces.

The measured streaming potential difference for distilled water was of the order of 8 millivolts when flow was present and showed no response to the BIOflex® pad. When the flow was cut off, the potential difference dropped to 0.59 millivolts. The potential difference for the flowing saline solution was of the order of 45 millivolts. The difference in measured voltage i.e. with the pad present less than without the pad, was of the order of 5 millivolts and decreased linearly with time over the 180 second run following the equation.

$$V = 6.35 - .04 * t$$

where V is in millivolts and t in seconds. The R squared value for the recession was 0.79. These results are plotted in Figure 2. This data should not be taken to be reliable due to the conditions of the experiment. However, it seems likely that more careful measurements will confirm that there is no difference in streaming potential with or without the BIOflex® pad for distilled water. It seems likely that there will be such a potential difference with flowing saline and that this difference will be related to the flow. No effects are expected when the flow is cut off. These preliminary streaming potential results are consistent with the more careful measurements on mass flow quoted above.

## DISCUSSION

It is of interest to speculate on the mechanism by which the BIOflex® pad affects the flow rate of the saline solution through the system. We know that there is a streaming potential set up in the experimental system. This indicates a low mobility double layer. It cannot be said that this low mobility layer is known to be present in the capillary portion. However, if it were present there, then Bxv forces on the flowing ions would act on the mobile ion so as to drive it into the double layer. This would in turn decrease the width of this layer and consequently increase the effective radius of the capillary. Moreover, the fact that the flow rate was affected when the meniscus of the large reservoir moved across the field of a pad wrapped around that reservoir can only mean that the surface tension between the saline solution and the reservoir wall was affected by the magnetic pad. It is well known (See *"Modern Electrochemistry",* Bockris and Reddy, Chapter 7, Volume 2; Plenum Press, New York 1970) that the surface tension changes are related to changes across the double layer at the boundary of the liquid. Thus, it is reasonable to infer that the BIOflex® pad does affect the double layer. The presence of a streaming potential by the pad implies a change in the mobility of the double layer. That conclusion is consistent with the observed change in mass flow through the capillary.

This paper was presented at the International Symposium Biomagnetology, Magnetotherapy and Postural Activity, Newport, R.I., U.S.A., May 29, 1989