# Research on Methods to Reduce the Influence of Medium Evaporation on Liquid Micro-Flow Facility

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**Abstract**

Liquid micro-flow facility in our country can achieve ultralow flow measurement as low as 100nL/min. In the detection process of liquid micro-flow facility, evaporation is significant for liquid at low flow rate, and if not controlled, the evaporation of the medium will be the main source of uncertainty for liquid micro-flow facility, so it is necessary to correct the evaporation effect during the test. Evaporation occurs mainly during the collection of liquid in the weighing container inside the balance, the effect of evaporation on flow is analysed, and obtains an evaluation method of the effect of reducing evaporation. The influence of balance drift on evaporation was excluded through experiment, and the research on evaporation under uninhibited conditions, evaporation under evaporation trap and oil film coverage were carried out. In addition, the evaporation studies under oil film coverage plus evaporation trap was also implemented. Finally, it is concluded that both the evaporation trap and the oil film covering can effectively inhibit the evaporation of medium, the optimal anti-evaporation method of the liquid micro-flow facility is to cover the paraffin oil film above 0.15g/cm$^2$, which can reduce the evaporation to 0.3μg/min, and the uncertainty to 0.12% ($k$=2) at the ultralow flow rate of the facility.
Keyword: Metrology, Liquid Micro-Flow, Evaporation, Evaporation Trap, Oil Film

## 1. Introduction

Liquid micro-flow measurement is widely used in biological, chemical, medical and micro-electro-mechanical systems (MEMS) industries, etc. As the requirements for fine process control have increased, the accuracy of liquid micro-flow measurement has also been greatly improved. Liquid micro flow facility in our country can achieve ultralow flow measurement as low as 100nL/min, and the evaporation is one of the main uncertainties. For liquid micro-flow facility, evaporation mainly occurs in the process of collecting the liquid into the weighing container inside the balance[1]. Generally, methods such as controlling the ambient temperature and humidity, increasing the sealing structure, evaporation traps and oil film coverage are adopted to reduce the evaporation of the liquid in the beaker[2-4]. Under the existing conditions of ambient temperature, humidity and sealing structure, the paper conducted an experimental research on several anti-evaporation methods such as evaporation trap, oil film covering and evaporation trap plus oil film covering, and applied the most effective anti-evaporation method to liquid micro-flow facility, which effectively improved the uncertainty of the facility under ultralow flow rate.

## 2. Research methods

### *2.1 The effect of evaporation on flow rate*

The effect of evaporation on flow rate can be expressed as:

$$E_{EVA} = \frac{q_{EVA} \times \rho}{Q} \quad (1)$$

The flow range of liquid micro-flow facility in our country is 100nL/min~150mL/min, without evaporation inhibition measures, the influence on the ultralow flow rate can reach 165%. Therefore, it is very important to inhibit evaporation for low flow, and it is necessary to take certain anti-evaporation measures.

### *2.2 Evaporation model analysis*

There are four cases reported in the national common formula of water surface evaporation. In the first example of the national common formula A, it can be concluded that the water surface evaporation and evaporation coefficient are influenced by many factors such as water, air temperature, humidity, air pressure and wind speed. The second national common formula B includes the effect of wind on water surface evaporation, and also includes the effect of water and air temperature difference on the evaporation of the water surface, so it comprehensively reflects the combined effect of free convection and forced convection in the process of water surface evaporation. In the third case of Li Wanyi formula model, the water-air pressure difference, wind speed and relative humidity play an important dominant role. The fourth type is an improved water surface evaporation model with strong adaptability based on the national common formula B, which mainly considering the influence of water-air pressure difference, wind speed and relative humidity. In summary, the main factors affecting the evaporation of medium are water-air temperature difference, humidity, air pressure, wind speed and so on.

From the literature, it can be seen that the strength of the wind speed, expressed in its strength of turbulent diffusion and the speed of dry and wet air exchange, the greater the wind speed, the stronger the turbulence, the faster the exchange of dry and wet air, so the evaporation is also greater. As there is a humidity difference between the water surface and its overhead and periphery, the relative humidity can reflect the speed of water vapour diffusion and exchange on the water surface. When the relative humidity is small, the water vapour diffusion and exchange outward fast, so the evaporation rate is large; when the relative humidity increases, it can inhibit the water molecules on the surface of the water overflow, but also weaken the water vapour diffusion and exchange strength,, so the evaporation rate decreases[5]. Since area is one of the main factors affecting evaporation, reducing the evaporation area as much as possible can theoretically also reduce evaporation. The ambient temperature in the laboratory is rapidly changing and the effect of ambient temperature must be considered[6]. The effect of water-air temperature difference on the evaporation coefficient decreases with increasing temperature difference[7].

*2.3 Comparison of evaporation inhibition methods*

It can be obtained from 2.2, under the environment of space confinement, standard atmospheric pressure and room temperature, short-term experiment can exclude the influence of water-air temperature difference, air pressure, humidity, wind speed and other factors. Several different measures to reduce medium evaporation, such as evaporation trap, oil film covering, evaporation trap and oil film covering, can be used to reduce the effect of evaporation on the flow rate. Evaporation trap are container with storage tanks around the beaker, increase the humidity of the air in the environment, as a way to reduce the evaporation. Oil film coverage that is covered with a certain thickness on the surface of the medium and itself evaporation is small oil film.

*2.4 Evaluation method for reducing evaporation effect*

We mainly use the evaporation rate to evaluate the evaporation effect, which can be expressed as:

$$q_{Eva} = \frac{|\Delta m_{Dec}|}{t_{Dec}} \qquad (2)$$

$\Delta m_{Dec}$ is the weight reduction in the descending period, and $t_{Dec}$ is the time measured in the descending period of $\Delta m_{Dec}$.

## 3. Experimental study

*3.1 Effect of balance drift on evaporation measurement*

Evaporation and the drift of the balance are inseparable during the experiment, and because the experiment has a long time at ultralow flow rate, the effective weighing value is small, and the stability of the balance during the measurement is very demanding, for this feature, the drift characteristics of the two balances were tested. The laboratory recorded the balance indication every 1s by placing standard weights of constant mass, generally, the continuous recording exceeds 8h, and the test is carried out at intervals of several days. It can be seen from the experiment in Figure 1 that the drift of the MCM36 balance is less than 0.1μg/min, and the drift of the MSA225S balance is less than 0.5μg/min. It can be seen from the experimental data that the drift of the two balances are at the same level, so balance drift has little effect, it is an uncertainty with uniform distribution into account.

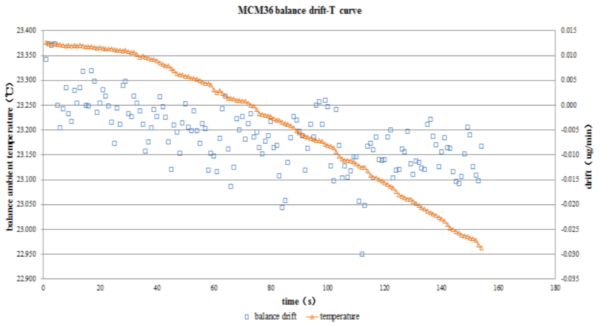


**Figure 1:** The relationship between drift of MCM36 balance and ambient temperature

*3.2 Uninhibited evaporation studies*

Physical factors affecting the evaporation speed mainly composed of temperature, area of the liquid surface, air flow rate above the liquid surface, etc. In addition, there are other factors such as humidity (saturation difference), air pressure, etc.

In order to ensure the reliability of the test data, the liquid micro-flow facility in the room temperature environment with draft shield of the Sartorius electronic balance for data collection, the closed space can avoid the liquid surface above the air flow to accelerate evaporation, under the condition that the temperature remains basically unchanged, the evaporation gradually increases with the decrease of humidity, evaporation and ambient humidity show a negative growth trend, The amount of evaporation decreases as the liquid surface area gradually decreases. Under the ultralow flow rate of the facility, the uncertainty generated by evaporation without inhibition measures can reach 95.18%($k$=2), so anti-evaporation measures must be taken to reduce the impact of uncertainty on the facility.

*3.3 Research on evaporation under evaporation trap*

The experiment was carried out on a Sartorius MCM36 electronic balance with a draft shield, the closed space to avoid accelerated evaporation by air flow above the liquid surface, the readability of the balance is 1μg, and the software automatically collected the balance indicated value every 0.2s, the experimental beaker is B-4#, and the surface area of the beaker is 314.16 mm$^2$, as shown in Figure 2, there is evaporation trap around the beaker. The ambient temperature around the beaker is 22.8 ℃, and the humidity is 20.9% RH. The calculated mass and drift curves with time are shown in Figure 3.

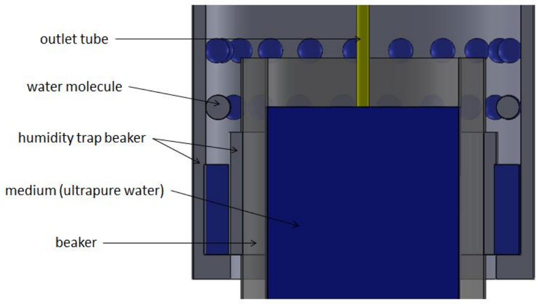


**Figure 2:** Schematic diagram of evaporation trap

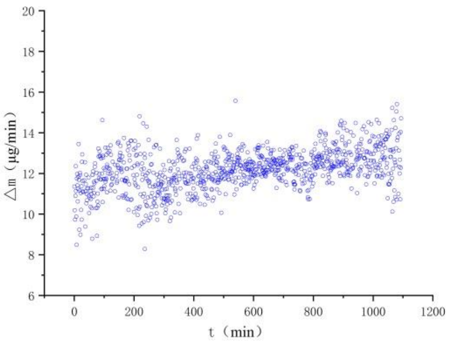


**Figure 3:** Schematic diagram of mass and drift under evaporation trap

It can be seen that under the condition of adding evaporation traps, the average evaporation is 12.18 μg/min, and the anti-evaporation effect is improved. At the ultralow flow rate of the facility, the uncertainty caused by evaporation reduced to 7%($k$=2), this anti-evaporation method is still not available.

*3.4 Research on evaporation under oil film covering*

1) The effect of oil film type on evaporation

There are about 4 or 5 kinds of mainstream oil films used as evaporation inhibitors at domestic and foreign, most of which use paraffin or silicone as inhibitors. In the experiment, paraffin and silicone were used for experiments, and Sartorius MCM36 electronic balance was used to collect test data, the weight of the beaker and the liquid are about 2/3 of the range of electronic balance. As shown in Figure 4, about 3mm thick paraffin or silicone was added to the beaker to carry out the experiment. The experiment is carried out on the premise that the experimental variable is only the oil film type, the results are shown in table 1.

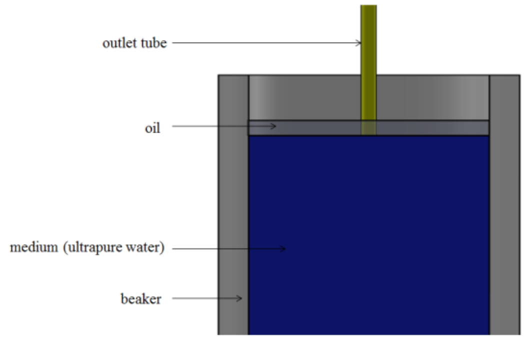


**Figure 4:** Schematic diagram of oil film coverage

**Table 1:** Statistics of different oil film evaporation data

| test date | oil film | maximum evaporation | minimum evaporation | average evaporation |
|---|---|---|---|---|
| / | / | μg/min | μg/min | μg/min |
| 6.25 | silicone oil | 4.40 | 2.05 | 2.78 |
| 6.28 | paraffin | 1.10 | 0.10 | 0.26 |
| 6.29 | paraffin | 1.70 | 0.18 | 0.44 |
| 7.1 | silicone oil | 4.81 | 2.51 | 3.33 |

It can be seen that when the oil film is silicone oil, the average evaporation amount is about 3 μg/min, and when the oil film is paraffin, the average evaporation is less than 0.3 μg/min, so the inhibition effect of paraffin is relatively good. At the ultralow flow rate of the facility, the uncertainty caused by evaporation is reduced to 0.12%($k$=2), and this method greatly reduces the uncertainty.

2) Influence of paraffin oil film concentration on evaporation

In order to verify the effect of paraffin oil film concentration on evaporation, different paraffin oil film concentrations need to be set during the test. The formula for calculating the paraffin oil film concentration is as follows:

$$c = \frac{n}{V} \qquad (3)$$

$n$ is the amount of substance of the solute and $V$ is the volume of the solution.

The experiment was set up with four different paraffin concentrations for the experiments, and the evaporation data are shown in Figure 5.

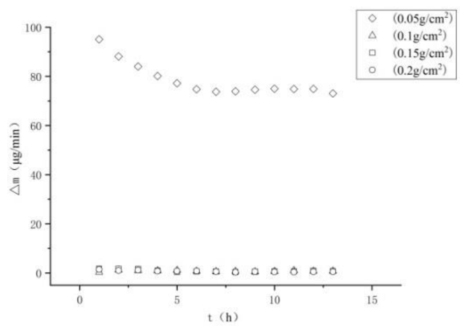


**Figure 5:** Schematic diagram of evaporation of different oil film concentrations

Therefore, when the paraffin concentration is 0.05g/cm$^2$, the average evaporation is 132.2μg/min, and when the paraffin concentration is 0.1g/cm$^2$~0.2g/cm$^2$, the average evaporation is 0.26μg/min~0.9μg/min, based on these datas, the paraffin concentration needs to be stabilized above 0.15g/cm$^2$ in order to have a better anti-evaporation effect.

*3.5 Study on evaporation capacity of oil film covering and evaporation trap*

It can be seen from the above content that both the evaporation trap and the oil film covering can inhibit evaporation and achieve the effect of inhibit evaporation. Therefore, as shown in Figure 6, we conduct experiments with oil film covering under the condition of setting evaporation traps to observe whether a better evaporation effect can be achieved. The variation curve of the calculated evaporation with time is shown in Figure 7.

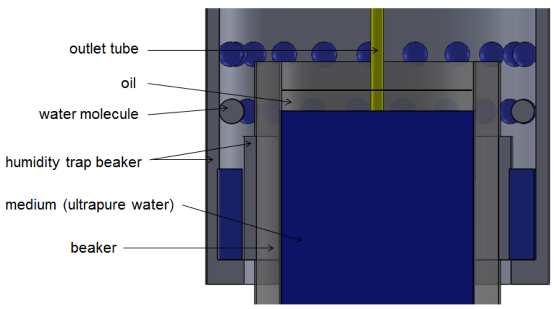


**Figure 6:** Schematic diagram of oil film coverage and evaporation trap

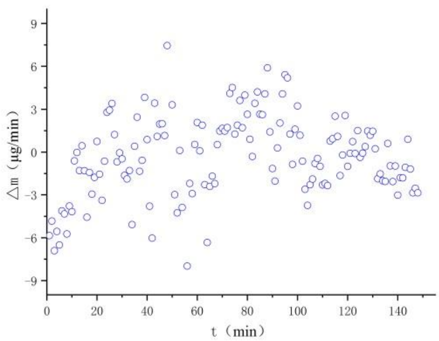


**Figure 7:** Schematic diagram of evaporation of oil film cover plus evaporation trap

It can be seen from the figure that when the experimental condition is the evaporation trap and oil film, evaporation value will produce negative value, and droplets will appear on the beaker wall, that is, this anti-evaporation measure will cause condensation on the beaker wall, which is not desirable.

## 4. Conclusion

Based on the premise that the balance drift has little effect on evaporation measurement, the influence of evaporation trap, oil film covering, evaporation and oil film covering on evaporation were verified through experiments, and finally the best anti-evaporation method for liquid micro-flow facility is obtained. , the evaporation is reduced to 0.3μg/min, and the uncertainty is reduced to 0.12% ($k$=2) at the ultralow flow rate. Due to the complicated operation of adding oil film in the experiment, and the overflow structure of the beaker cannot add oil film, it is not considered at large flow rate. The method of adding evaporation trap can be considered to inhibit evaporation. After calculation, it can be concluded that anti-evaporation measures should be added for flow rate below 100 μL/min, so that the uncertainty caused by evaporation is not one of the main sources.

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