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Experimental investigation on two-stage thermoelectric cooling system adopted in isoelectric focusing

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ABSTRACT

Performance of temperature control is crucial to the operation of isoelectric focusing equipment (IEF). In this paper, two-stage thermoelectric cooling module (TEM) is proposed to be adopted in IEF to realize prompt and precise temperature control as well as low focusing temperature (T_f). Three different prototypes including *HP* + *baffle*, *AL* + *baffle* and *HP* + *fin* are developed to obtain optimal design. Experimental setups of these prototypes are built up to test their performance. Temperature distribution on cooling plate, COP and air temperature in bottom chamber with respect to different T_fs are adopted as performance indices to evaluate performance of these prototypes. Experimental results show that aluminum plate with heat pipes, used as cooling plate, can improve its temperature uniformity. Moreover, fin-type heat sink with baffle can effectively dissipate heat on the hot side of TEM with little impact on the other parts of IEF. The T_f of *HP* + *baffle* can be kept at 10 °C. And its COP can reach 2.0 under general working condition.

Etude expérimentale d'un système de refroidissement thermoélectrique biétagé adopté dans la focalisation isoélectrique

Mots clés : Modèle de refroidissement thermoéléctrique (TEM) biétagé ; Caloduc ; Chicane ; COP

1. Introduction

Isoelectric focusing equipment (IEF) is widely adopted in scientific research especially in proteomic engineering. It realizes the separation of different protein molecules with different isoelectric points (Sluszny and Yeung, 2004). A thin polyacrylamide gel, containing an immobilized pH gradient (IPG), is used as a molecular sieve in modern IEF methods (Friedman et al., 2009). Proteins are introduced into the IPG

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Nomenclature

A	Sectional area (mm^2)
H	Height (mm)
I	Current (A)
K	Thermal conductance (WK^{-1})
L	Length (mm)
N	number
R	Electrical resistance (Ω)
T	Temperature (K or °C)
U	Voltage (V)
W	Width (mm)

Greek letters

a	Seebeck voltage (VK^{-1})
λ	Thermal conductivity ($Wm^{-1}K^{-1}$)
σ	Electrical conductivity (Ωm^{-1})

Subscripts

a	air
set	Set temperature
f	Focusing temperature
c	Cold stage
h	Hot stage
m	Medium
e	environment
cp	Cooling plate
P	Production
in	input
power	Power driver

strip. The commercial IPG strips generally have the lengths from 7 cm to 24 cm and they are placed in high electric field (Garfin, 2001; Healthcare, 2007). So the different molecules of the proteins in IPG strips can be separated in the electrical field. Temperature control is crucial to the operation of IEF: in the first place, Joule heat is produced by IPG strips under high electric field strength which has disadvantageous effect on protein separation (Friedman et al., 2009; Righetti et al., 2011); Secondly, the mobility of protein significantly depends on focusing temperature (generally from 10 °C to 30 °C), (Görg et al., 1991).

At present, thermoelectric cooling (TEC) system is widely used as temperature control configuration in IEF due to the merits of prompt response and accurate control (Huang and Duang, 2000; Zhou and Yu, 2012). Such systems have been commercialized by several companies such as GE (Healthcare, 2007) and Hoefer (Smejkal and Bauer, 2010). Aluminum or cooper plate is generally employed as cooling plate with 1–12 IPG strips in the devices. The IPG strips are placed on the horizontal cooling plate connected with thermoelectric module (TEM). In order to realize stable operation of IEF system, three performance indices for TEC system are important: the first one is the focusing temperature range of IEF. It is because the protein exhibits typical temperature related to mobility and the temperature range is general ranged from 10 °C to 30 °C. However, the low focusing temperature below 15 °C of general IEF with TEC system could not be kept due to limited volume of hot side heat sink and single-stage TEM. The second one is the temperature distribution on cooling plate, which determines whether the IPG strip has uniform temperature distribution. It is estimated that the heat flux of IPG strip is around 700 Wm^{-2} (Healthcare, 2007)while the cooling capacity of commercial TEM is around 4000 Wm^{-2} (Shen et al., 2013). So it is not cost-effective to fully place the TEMs under the cooling plate. The non-full placement of TEMs would lead the non-uniform temperature distribution along the IPG strips. This kind of problem also exists in thermoelectric radiant air-conditions system (Shen et al., 2013) and solar thermoelectric generator (Kraemer et al., 2012). And then increasing the thickness of cooling plate would improve the uniform temperature distribution along the IPG strips (Healthcare, 2007). And yet, the thermal capacity of cooling plate would be increased, which leads to the decreasing of heating or cooling rate. The third is cooling rate. Cooling rate refers to the rate of temperature decrease, which can reflect the prompt of control system. Thin cooling plate, which leads to low thermal capacity, and high heat transfer coefficient of fin-type heat sink can improve cooling rate, however, the non-uniform temperature distribution on cooling plate and large volume of heat sink are not accepted in commercial IEF. The last one is an effectively heat dissipation on the hot side of TEM, which significantly affects COP, lowest T_f and cooling rate of the system. Moreover, the heat dissipation on hot side of TEM is much more than the cooling load absorbed from cooling plate, on the cold side. Generally, an IEF integrated with high voltage power supply and chip of temperature control became a compactable volume (Healthcare, 2007). At the same time, the chips of high voltage supply and temperature control cannot work at high temperature. As a result, it is important to develop high-efficiency heat sink without impacting other parts of IEF such as the chips of power supply and temperature control (Healthcare, 2007).

Widely adopted TEC system in IEF is common single-stage TEC, however, the focusing temperature of IEF could not keep below 15 °C (Healthcare, 2007). Meanwhile, there are rare results on performance parameters of temperature distribution on cooling plate, COP and air temperature in bottom chamber. In order to realize prompt, accurate and high efficient temperature control as well as large focusing temperature range, two-stage TEM system with high-efficiency cooling plate and heat sink is developed in this paper. This system contains two-stage TEMs, cooling plate, hot-side heat sink and PID temperature control. The aluminum (AL) plates with and without heat pipes are tested as cooling plate of IPG strips. Meanwhile, the fin-type heat sinks with and without baffle are also tested as hot side heat sink.

2. System description

Configuration of two-stage TEM system of IEF is shown in Fig. 1. It is comprised of temperature control unit and two-stage TEM unit.

2.1. Two-stage TEM unit

Configuration of two-stage TEM unit is shown in Fig. 2. It is mainly consist of cooling plate for 1–12 IPG strips, two pieces of two-stage TEMs, heat sink, bottom and top chambers. 1–12