DOI: 10.63527/1607-8829-2026-1-84-92

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Thermoelectric Device for Iontophoresis

A thermoelectric device has been developed for controlled temperature support of iontophoresis procedures. Its use in standard medical iontophoresis devices significantly expands their therapeutic capabilities and improves treatment comfort. The proposed device stabilies the temperature of electrodes and hydrophilic pads in the range from 15 to 45°C with high control accuracy, optimizing the transdermal drug delivery. The use of controlled heating or cooling makes it possible to influence the rate of diffusion of drugs, the permeability of biological tissues, local blood circulation and the efficiency of therapeutic effects. The use of reduced temperatures for localization of drugs in the zone of influence, reduction of inflammatory processes and increase of treatment efficiency in various pathological conditions is especially promising. The proposed thermoelectric device design utilizes Peltier modules, a heat exchange system, and automatic temperature control, ensuring stable operation in various modes. The device can be used in conjunction with standard iontophoresis devices without any design modifications. The developed thermoelectric device enables the implementation of new temperature-controlled iontophoresis modes, opening up prospects for improving the effectiveness of physiotherapy procedures and developing new medical technologies.

Keywords: iontophoresis, thermoelectrode, thermoelectric module, thermoelectric device, heat exchanger, temperature range, thermostat, cooling, heating, biological tissue, transdermal drug delivery, efficiency of therapeutic effect.

Introduction

Iontophoresis was introduced into medical practice in the early 19th century, when medicinal substances were first used in combination with direct electric current to affect the

Citation: M.V. Havryliuk, R.R. Kobylianskyi, I.A. Konstantynovych (2026). Thermoelectric Device for Iontophoresis. *Journal of Thermoelectricity*, (1), 84–92. https://doi.org/10.63527/1607-8829-2026-1-84-92

Received: 16.02.2026; Revised: 02.03.2026; Published: 31.03.2026

patient's body. Currently, other types of currents and modified methods of transdermal drug delivery are widely used.

With iontophoresis, medicinal substances penetrate to a relatively shallow skin depth: immediately after the procedure, they are found primarily in the epidermis and dermis, with a small amount also in the subcutaneous tissue. From these biological tissues medicinal substances introduced via iontophoresis enter the lymph and bloodstream and are distributed throughout the body, although they primarily accumulate in the tissues and organs of the treatment area. During iontophoresis, a relatively small amount of medicinal substance enters the body – approximately 1–10% of its content in the solution located on the thermoelectrode pad. The amount of substance introduced is significantly influenced by the physicochemical properties of the medicinal products, the current parameters, the duration of the procedure, and the temperature of the medicinal solution and tissues in the treatment area [1-3].

Temperature is known to be an important factor significantly affecting the effectiveness of iontophoresis. In [1], the effect of local cooling before the iontophoresis procedure using a 10-minute ice massage was investigated. Investigation showed that iontophoresis significantly increased local blood flow, while pre-cooling reduced tissue perfusion, which significantly affected the concentration of the drug in subcutaneous structures and the nature of its distribution [4–6]. In [5], the effect of local cooling during iontophoresis of norepinephrine was studied. It was found that pre-cooling changes the tissue response to the procedure, changes the temperature thresholds of sensitivity, enhances the response to cold and affects local metabolic processes in the tissues. The results obtained indicate the possibility of controlling the therapeutic effect of iontophoresis due to the temperature effect [7–9]. Furthermore, modern review papers note that factors such as temperature, blood flow, tissue conductivity, and skin permeability significantly influence the effectiveness of iontophoresis. It has been shown that temperature changes alter the rate of drug diffusion, ion movement, and the electrical conductivity of biological tissues, which directly impacts the effectiveness of transdermal drug delivery [10–18]. The iontophoresis procedure typically lasts 20–30 minutes. Obviously, over a relatively long period of time, the temperature of the wet pad changes depending on the ambient temperature, and it can reduce the comfort of the procedure and influence the effectiveness of drug delivery. For different drugs, there are specific temperature ranges within which drug penetration is enhanced or therapeutic effects are optimized. For example, some drugs are better administered at temperatures lower than skin temperature. In particular, in cosmetology, medicinal substances are administered at temperatures around +17°C. Also, there are many different designs of iontophoresis devices that allow for variable electrode temperature. Some of these devices only provide heating of the probes, while others use ice or cooled pads to cool the electrodes. However, such cooling methods are difficult to control, not stable enough, and ineffective. All of the above makes the research and production of advanced physiotherapeutic thermoelectric equipment extremely relevant.

Therefore, the purpose of this work is to create a thermoelectric device for iontophoresis, which will significantly increase the effectiveness of treatment, expand the functionality of existing physiotherapy systems, and improve the comfort of the procedure.

Technical characteristics and design features of a thermoelectric device for iontophoresis

A promising direction in the development of thermoelectricity is the development, creation and manufacture of thermoelectric devices for medicine [19–28]. In particular, the efficiency of iontophoresis devices can be significantly improved by using thermoelectric cooling and heating, providing a controlled temperature regime for the administration of drugs. As shown above, temperature significantly affects the effectiveness of iontophoresis, changing blood flow, biological tissue permeability, diffusion rate, and drug ion movement. The use of cooling before iontophoresis allows for changes in tissue perfusion and drug concentration in the injection area, while local heating can enhance drug penetration into biological tissues. Thus, the use of controlled temperature regime is a promising approach to improving the efficiency of iontophoresis procedures. Therefore, the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine has developed a thermoelectric device for iontophoresis that maintains the temperature of the electrode plate and hydrophilic pad within a range of (15 ÷ 45) °C with an accuracy of ±0.5°C.

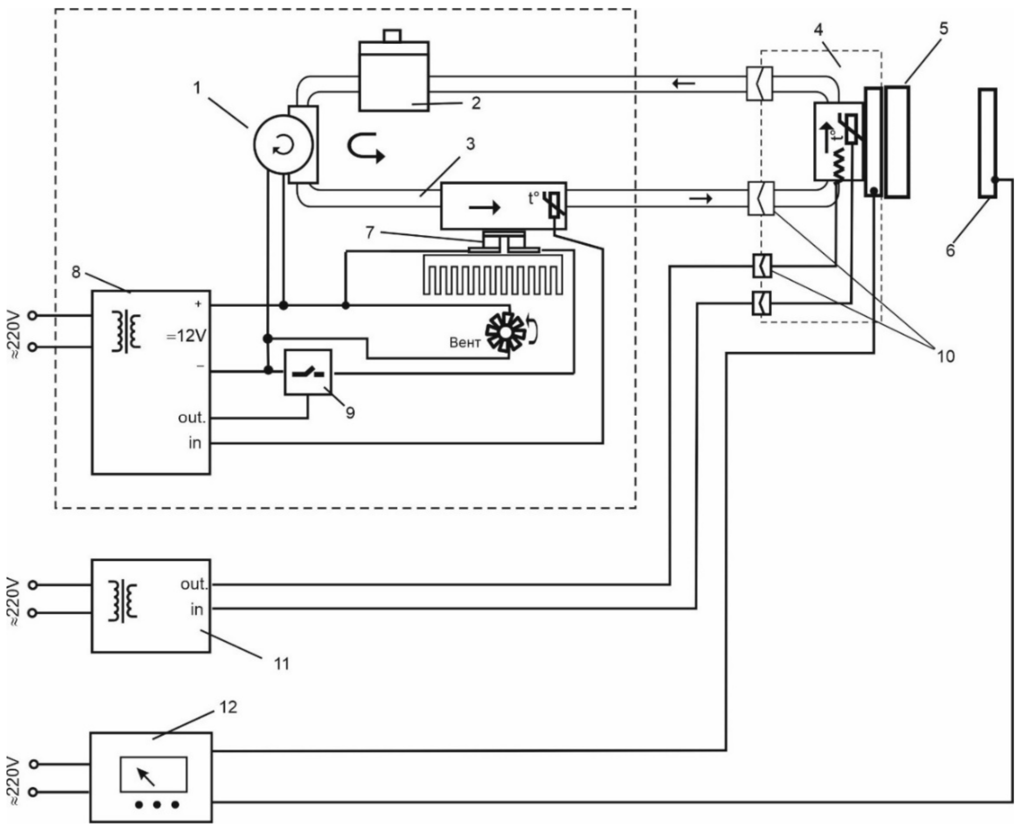

Fig. 1. Schematic diagram of a thermoelectric device for iontophoresis
1 – water pump, 2 – expansion tank, 3 – heat exchange system,
4 – iontophoresis thermoelectrode (anode), 5 – hydrophilic pad for drugs,
6 – iontophoresis electrode (cathode), 7 – Peltier modules,
8 – power supply and thermal control of the heat exchange system, 9 – switchboard,
10 – electrical and liquid connectors, 11 – thermoelectrode heating unit,
12 – standard iontophoresis device

As can be seen from Fig. 1, the thermoelectric device for iontophoresis consists of probe electrodes, a control unit including a heat exchange unit with thermostats, and a standard unit - the iontophoresis device. The probe electrode is made of a thin, flexible lead plate, on the outside of which a resistive heater, a tubular liquid heat exchanger, a temperature sensor are attached, and a conductor is connected to the iontophoresis device. The probe electrode is made of a thin elastic lead plate, on the outside of which a resistive heater, a tubular liquid heat exchanger, a temperature sensor are attached, and a conductor is connected to the iontophoresis device.

To improve the thermal contact of the heating element, heat exchanger and temperature sensor with the probe plate, its outer side is filled with silicone sealant. The hoses of the tubular heat exchanger are connected to a thermoelectric liquid cooler with a circulation pump. The probe itself, via a cable and plug, is connected to a standard iontophoresis device.

The electrical conductors of the temperature sensor and heating element are galvanically isolated from the probe's lead plate, ensuring the electrical safety of the procedure. The probe is temperature-controlled in the "on-off" mode within the specified temperatures. The thermoelectric liquid cooler is made as a separate unit, which uses Peltier modules with heat removal from the hot side using a radiator with a fan.

Table

Technical characteristics of a thermoelectric device for iontophoresis

Technical characteristics of device	Parameter values
Time to enter the mode, min	10
Continuous operating time of the device, hrs	8
Operating temperature range, °C	15 ÷ 45
Maximum device power, W	150
Device supply voltage, V	~240
Thermoelectrode dimensions, mm	150×80×5
Dimensions of heating control unit, mm	80×70×110
Dimensions of cooling control unit, mm	200×200×80
Weight of heating control unit, kg	0.75
Weight of cooling control unit, kg	3

The cooler has its own temperature control system for the coolant, which is typically distilled water. The response time of liquid heat exchangers is quite high, so when cooling the probes to temperatures below body temperature, the liquid is first cooled to a temperature below the required value, after which a resistive heater within the probe itself ensures that the hydrophilic pad temperature is precisely adjusted to the set value. This design of the probes is simple, reliable and convenient for sterilization, as the probes withstand standard sterilization procedures. For the option of using the probes only in the heating mode, the cooling unit may not be used. This mode of operation is used much more often in clinical practice. The technical parameters of the thermoelectric device for iontophoresis are given in the table.

Fig. 2 Shows the appearance of an experimental sample of an iontophoresis device.

Fig 2. Appearance of heated probes for iontophoresis

The thermoelectrode design is as close as possible to standard ones, allowing the developed thermoelectric device to be used in conjunction with standard iontophoresis equipment already in use in medical institutions. Furthermore, the use of thermoelectric temperature control enables the implementation of new treatment modes, including temperature-controlled iontophoresis, cryo-iontophoresis, and combined heating-cooling modes, opening up the possibility of increasing the effectiveness of physiotherapy procedures.

Conclusions

1. A design of a thermoelectric device for iontophoresis has been developed with the possibility of controlled heating and cooling of electrodes in the temperature range (15 ÷ 45) °C with an accuracy of ±0.5 °C, which ensures stable conditions for conducting physiotherapeutic procedures. It has been shown that the use of controlled temperature regime during iontophoresis allows influencing the permeability of biological tissues, blood circulation, the rate of diffusion of drugs and the effectiveness of their transdermal administration, which is confirmed by modern experimental studies. The proposed design of the thermoelectric device allows for the implementation of new physiotherapeutic modes, in particular, thermally controlled iontophoresis, local cooling, and combined heating-cooling modes.
2. It was established that the developed thermoelectric device can be used in conjunction with existing models of standard iontophoresis equipment without the need for their structural modification. The use of thermoelectric Peltier modules provides compactness, reliability and high accuracy of temperature control, which increases the effectiveness of treatment and comfort of procedures. The proposed approach opens up prospects for the creation of new medical technologies of thermally controlled iontophoresis, which can be used in physiotherapy, rehabilitation medicine, cosmetology, dermatology and other areas of medical practice.

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Термоелектричний прилад для іонофорезу

Розроблено термоелектричний прилад для керованого температурного забезпечення процедур іонофорезу, використання якого у складі стандартних медичних апаратів іонофорезу дозволяє суттєво розширити їх терапевтичні можливості та покращити комфортність проведення процедур. Запропонований пристрій забезпечує стабілізацію температури електродів та гідрофільних прокладок у діапазоні від 15 до 45°C із високою точністю регулювання, що дозволяє оптимізувати процес трансдермального введення лікарських речовин. Застосування керованого нагрівання або охолодження дає можливість впливати на швидкість дифузії лікарських препаратів, проникність біологічних тканин, локальний кровообіг та ефективність терапевтичного впливу. Особливо перспективним є використання знижених температур для локалізації лікарських препаратів у зоні впливу, зменшення запальних процесів та підвищення ефективності лікування при різних патологічних станах. Запропонована конструкція термоелектричного приладу базується на використанні модулів Пельтьє, системи теплообміну та автоматичного терморегулювання, що забезпечує стабільну роботу пристрою у різних режимах. Прилад може використовуватись сумісно зі стандартними апаратами іонофорезу без їх конструктивної модифікації. Розроблений термоелектричний прилад дозволяє реалізувати нові режими термокерованого іонофорезу, що відкриває перспективи підвищення ефективності фізіотерапевтичних процедур та створення нових медичних технологій.

Keywords: іонофорез, термоелектрод, термоелектричний модуль, термоелектричний прилад, теплообмінник, температурний діапазон, терморегулятор, охолодження, нагрів, біологічна тканина, трансдермальна доставка лікарських речовин, ефективність терапевтичного впливу.