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Implementation on Medical Infusion Pump with Constant Warm Temperature Flow

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Abstract. During the abdominal surgery, as well as other kinds of surgeries, trauma flushing with warm sterilized normal saline can not only prevent infection, avoid arrhythmia caused by lower body temperature, but can shorten the postoperative recovery time. In order to achieve different normal saline water-flow with constant temperature (usually 37°C) in different environments during different seasons, a medical infusion pump with adjustable water-flow having constant temperature was designed. This paper mainly gave researches on the implementation of such an infusion pump. In the paper, we also estimated the power consumption based upon the law of conservation of energy and the heat calculation formula. By using the fuzzy proportional-integral-derivative (PID) control algorithm, we achieved adjustable constant sterilized normal saline flow with 37°C constant temperature.

Keywords: Infusion pump, Constant temperature control, Fuzzy PID, Power consumption estimate

1. Introduction

In modern society, with the rapid urbanization process, the pace of people's life becomes faster than ever before. People are busy all day on working and social intercourse, giving less time to pay attention on their health. This leads more and more people to suffer from all kinds of diseases. Meanwhile, with the development of science and technology, surgical operation becomes main methods to treat such diseases generally. During all kinds of surgery or after the surgery, it always needs doing trauma flushing and/or cleaning using warm sterilized normal saline (usually 37°C). This process can not only effectively prevent infection by removing necrotic tissue, exudate, blood clots and pus, reducing wound infection rate and mortality, shortening the recovery process after the surgery, but also can prevent serious arrhythmias, such as ventricular fibrillation, due to lower body temperature. The medical infusion pump with constant warm temperature normal saline flow is a good device for controlling the temperature, the flushing pressure, and the velocity of the normal saline flow. It is considered to be safety and is easy to operate for the doctors. It can also reduce doctor's workload, and increase their efficiencies.

In this paper, we will mainly introduce how to implementation of such an infusion pump in detail, including designing of the water-bag, the aluminium plates, configuration of the sensors, temperature control algorithm. Power consumption estimation based upon the heat calculation formula, and the law of conservation of energy is also provided.

2. System Implementation

In order to realize constant warm temperature control, an infusion pump was designed, and the schematic diagram was shown in Fig.1. The main components of the system included: (1) a water-bag with a serpentine shape, inside of which flowed the sterilized normal saline needing to be heated up to about 37°C from the

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room temperature, which would be changed during different seasons. Its volume was about 0.3 litre (L); (2) a peristaltic pump, which was a type of positive displacement pump used in our research for pumping normal saline for the surgery use. Such a process was called peristalsis, something like the gastrointestinal tract of the animals; (3) Two aluminium plates, paralleled in circuits acting as the heaters to warm the normal saline up to about 37°C; (4) A pressure sensor to determine the pressure inside the pipes, and three temperature sensors to determine how to control the heating energy; (5) A micro control unit (MCU) and other interface parts, including a liquid crystal display (LCD) display, several setting buttons, and a voiced light alarm component.

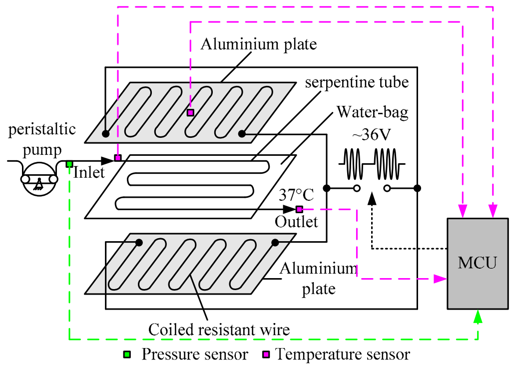

Fig. 1: The schematic diagram of the infusion pump

Two aluminium plates, inside of which were coiled resistant wires, were place on and under the water-bag with serpentine shape to delay flow time so as to let normal saline be heated gradually. The voltage used to heat the coiled resistant wires was alternating current (AC) 36V with a certain duty cycle, which was controlled by a MCU. This modulated voltage was selected because it was a safe one in medical applications for the doctors and the patients according to regulations on supervision and management to medical instruments. The fuzzy proportional-integral-derivative (PID) algorithm was applied to realize the heating energy control [1,2]. The actual temperature, which approximated 37°C, at the outlet port, the pressure inside the pipe and the velocity were displayed on the LCD. If the temperature was higher than 40°C, it would give a voiced light alarm for emergent purpose.

2.1. Designing of the Water-Bag

The water bag, whose inlet was connected to the peristaltic pump, was designed as a serpentine type heat exchanger. The velocity of normal saline inside the soft pipe could be altered by change the rotation speed of the peristaltic pump. The flow of normal saline went ahead like a serpentine to expand the heating time with the two aluminium plates. The temperature of normal saline at the outlet port was about 37°C, which was the optimal one for the patient when performing the surgery, though the velocity of normal saline altered.

2.2. Designing of the Aluminium Plates

In order to provide heat source, two aluminium plates identical in size and power, the water-bag being placed between them like a sandwich, was specially designed. Inside each aluminium plate was coiled electric resistant wires with two lead wires placed outside, one taking as an anode, and another one taking as a cathode. To ensure safety, such a heater was heated using alternating current (AC) 36V, not main electricity 220V instead.

2.3. Configuration of the Sensors

In our application, a pressure sensor and three temperature sensors were used. The pressure sensor was placed under the pipe at the inlet of the water-bag to indicate whether the normal saline was flowing, so as to let the MCU to decide how to provide the heat energy. The first temperature sensor was placed on the surface of the pipe at the inlet of the water-bag to measure the temperature here (T_i, initial normal saline temperature), the second one being place on the surface at the outlet of the water-bag to provide the temperature at this point (T_f, final normal saline temperature), and the third one on one of the aluminium plate's surface center to give the temperature of the heater (T_h, temperature of the heater). These three temperatures were all used for the MCU to decide how to heat the aluminium plates, so as to reach the aim, i.e., 37°C warm normal saline for the surgery.

2.4. Temperature Control Algorithm

After the power switch of the device was turned on, the MCU started to heat the two aluminium plates until T_f approximated 37°C, which would last about 2 minutes. After that, the MCU tried to keep this constant temperature using a temperature control algorithm. When the tap was opened, the water flows out of the pipe, the pressure sensor could catch this variation immediately. At this time, T_f, T_i, and T_h would begin to change. Correspondingly, the temperature control algorithm should be executed to keep T_f constant. The main idea of the algorithm was that the MCU always performed monitoring the temperatures of these three sensors. If the actual value of T_f was a little higher than 37°C, 37.5°C for example, the MCU told the aluminium heater to stop heating immediately. On the contrary, if the actual vale of T_f was a little lower than 37°C, 36.5°C for example, the MCU told the heater to begin to heat with full duty cycle of the AC voltage until the actual value of T_f equalled about 37°C, and began to heat with small duty cycle of the AC voltage.

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3. Power Consumption Estimation

Please acknowledge collaborators or anyone who has helped with the paper at the end of the text.

Let the flow rate of water be Q (L/min), time normal saline used T (min), initial normal saline temperature at the inlet port t_0 (℃). Then the power consumption can be estimated based upon the hypothesis that flowing normal saline was heated directly by electrical current for the purpose that temperature at the outlet port was about 37℃.

The volume of normal saline after time *T*, normal saline quality could be calculated using the formula m = ρV. If normal saline was just heated by electric current, the heat absorbed due to temperature increased from t_0 (℃) to t_1 (℃) could be calculated. This heat absorbed equalled the consumption of electric energy. Then electric power could also be obtained. The volume of normal saline (V) used per minute,

$$V=QL/min\times 1min=QL=Q*10^{-3}\ (m^3) \quad (1)$$

The quality of normal saline (m_1) used per minute,

$$m_1=\rho V=1\times 10^3 kg/m^3\times Q*10^{-3}m^3=Q\ (kg) \quad (2)$$

The quality of normal saline of total T (min) time,

$$m=T\times m_1=T\times Q=TQ\ (kg) \quad (3)$$

According to the heat calculation formula, the heat absorbed W_a due to normal saline temperature increase from t_0 to t_1,

$$W_a = cm(t_1-t_0) = 4.2\times 10^3\ J/(kg\bullet ℃)\times TQ\ (kg)\times(t_1-t_0) = 4.2*(t_1-t_0)*TQ*10^3\ (J) \quad (4)$$

Then, according to the law of conservation of energy, the least consumption electric energy W_e equalled W_a, Electrical power P should be provided,

$$P=\frac{W_e}{t}=\frac{W_a}{t}=\frac{4.2*(t_1-t_0)*TQ*10^3(J)}{T*60(s)} \quad (5)$$

In our application, t_1=37℃, Q changed from 0.1L/min to 0.5L/min, and t_0 equalled the ambient temperature inside the surgery room. Took Q be 0.5L/min, t_0 be 20℃, t_1 be 37℃ as an example,

$$P=\frac{4.2*(37-20)*0.5*10^3(J)}{60(s)}=595W \quad (6)$$

Table 1 showed the estimation of power consumption P under different initial temperature t_0 at the inlet port and different flow rate Q.

Table 1: Estimation of power consumption

t_0 @Inlet (℃)	Q (l/min)	P (W)	t_0 @Inlet (℃)	Q (l/min)	P (W)
20	0.1	119	10	0.1	189
20	0.2	238	10	0.2	378
20	0.3	357	10	0.3	567
20	0.4	476	10	0.4	756
20	0.5	595	10	0.5	945

4. Result and conclusion

In the paper, we presented a method to implement a medical infusion pump with constant warm temperature flow. After the main components of the device was described, we introduced the general designing of the water-bag, two aluminium plates, configuration of a pressure sensor and three temperature sensors, and the temperature control algorithm to reach our aim. Then, we tried to give estimation of the power we needed based upon the heat calculation formula and the law of conservation of energy. This will provide the basis for selecting the transformer, which performs converting the main AC 220V to AC 36V for our safe application. From the Table 1, the power consumption of the device should be no less than 945W when the initial normal saline temperature reached 10°C, and the flow rate increased to 0.5L per minute.

Due to the fact that it could provide normal saline flow with a constant warm temperature (37°C) in different environments during different seasons, this medical infusion pump would benefit, I think, both the patients and the doctors in the hospital.

5. Acknowledgements

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6. References

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