Optimization of Power Consumption for Centrifugation Process Based on Attenuation Measurements

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Optimization of Power Consumption for Centrifugation Process Based on Attenuation Measurements

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Abstract. The main objective of this research is to produce a mathematical model that allows decreasing the electrical power consumption of centrifugation process based on attenuation measurements. The centrifugation time for desired separation efficiency may be measured to determine the power consumed of laboratory centrifuge device. The power consumption is one of several parameters that affect the system reliability and productivity. Attenuation measurements of wave propagated through blood sample during centrifugation process were used indirectly to measure the power consumption of device. A mathematical model for power consumption was derived and used to modify the speed profile of centrifuge controller. The power consumption model derived based on attenuation measurements has successfully save the power consumption of centrifugation process keeping high separation efficiency. 18kW.h monthly for 100 daily time device operation had been saved using the proposed model.

Index Terms- power consumption, attenuation measurements, velocity profile

1. Introduction

The centrifugal devices can use in a variety of medical and industrial applications. Typically, the power consumption, capacity, speed of rotation, separation precision and the centrifugation time are essential technical parameters of the centrifuge device, and hence their reliability may affect the system reliability and productivity. For this reason, centrifugation process is often obeying to developments and improvements continuously.

Continuing from our previous research [1], we derived a modified period of velocity profile model (spinning period) which leads to decreasing the power consumption of laboratory centrifuge devices. The new model has ability to estimate the power consumed for pre-defined separation efficiency. The

laboratory diagnosis of blood depends on separation efficiency which is done by means of centrifugal force and the spinning time for the blood sample.
The current method of separating contents of a blood sample is not accurate in terms of centrifugation force and time. These variables are evaluated based on sedimentation theory, which calculates the sedimentation time based on higher particle density (red blood cells) and depth of sedimentation [2]. Therefore, about 0.5ml volume of a 1ml blood sample, the current centrifugation time is five minutes (also as recommended by the centrifuge device recommended manufacturer). To minimize or eliminate such uncertainties (due to damage of some red blood cells) from the process, we have developed a new technique that accurately predicts the required time for the separation then control the velocity profile period of centrifuge device. This technique is based on measuring the attenuation of the wave propagated through liquid its density varies with time of spinning[3], [4]. Separation efficiency of blood and plasma is evaluated empirically by percentage count for the red blood cells, white blood cells, HCT, and platelets in a sample using blood analyzer device (cell-dyne 1800). Experimental data was used to calculate the power consumption during the time taken for accurate separation.
The schematic diagram of experimental attenuation measurements is shown in figure 1. Human blood was drawn from 84 healthy volunteers, 23 women and 61 men; their HCT values ranged from 21% to 53.7%; age range, 21 to 50 years. Samples of plasma were prepared using a serum separator tube (EDTA (K2); demophorius Ltd, cypus, EU, UK).
Figure 2 shows the mathematical model deriving structure. This method can also be applied to other purpose of centrifugal device, such as measurements of solid contents in liquid and sedimentation measurements [5].
Since the installation of additional measurement sensors may be costly and the sensors can also reduce the device reliability, they are not always the most cost-effective solution for the separation percentage monitoring of a centrifuge device. For this reason, the centrifuge velocity profile controller must be modified according to new mathematical model. The modified period of linear velocity profile and mathematical model derivation are seen in next sections. Another section of your paper
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2. Linear Velocity Profile

The choice of method for any particular system is a complex decision, in which the conflicting demands of high performance and low cost are evident. For example, an exponential ramp may be required for optimum acceleration, but its implementation is expensive and so the designer may compromise with a linear ramp, which is available at low cost. The linear profile is the common practicing to approximate the velocity profile by linear functions figure 3a. However, this approximation

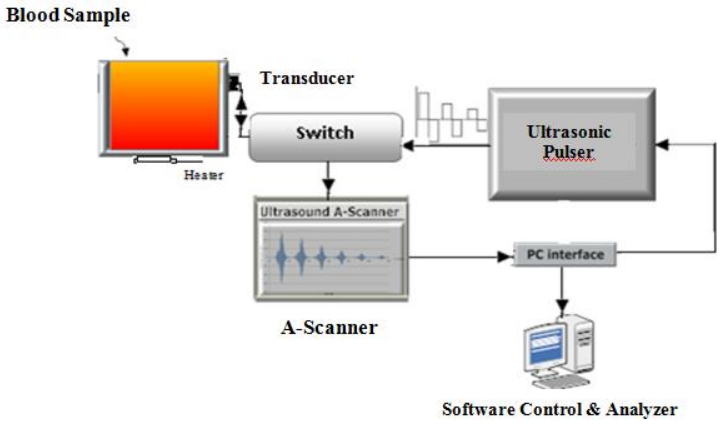


Fig. 1. Schematic diagram of experimental apparatus.

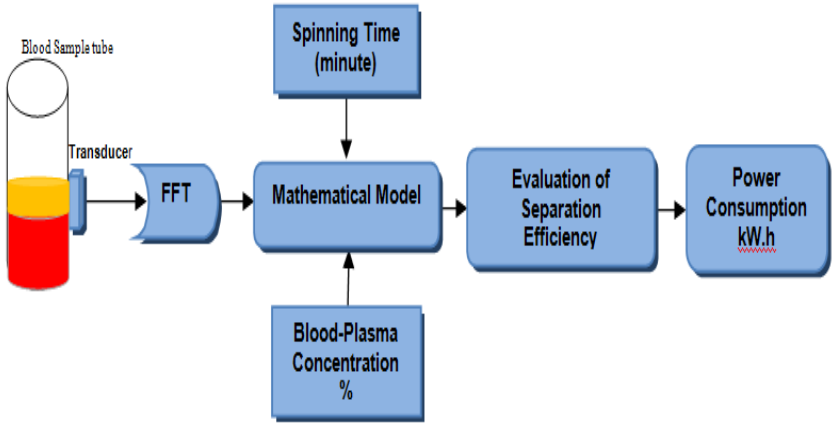
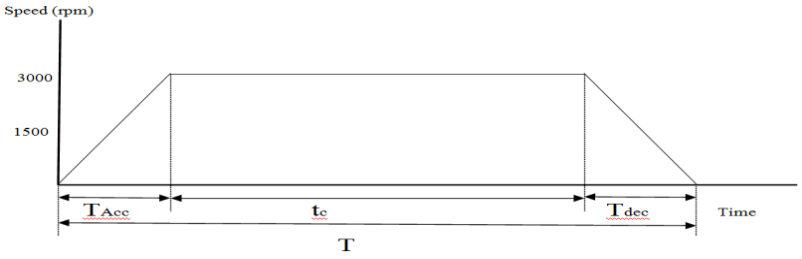
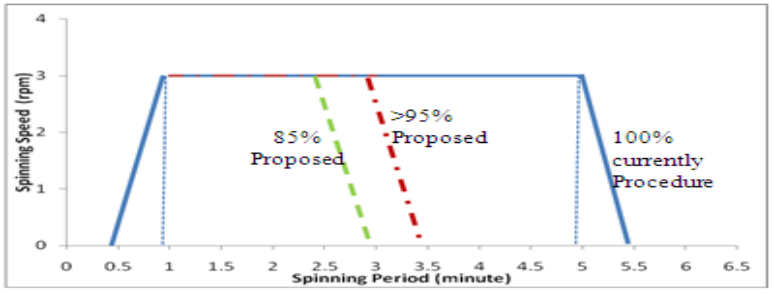


Figure 2. The deriving structure of mathematical model



(a)



(b)

Figure 3. Linear velocity profile (a), and spinning period for currently and proposed procedure (b).

imposes a constraint on the system's maximum stepping rate, which becomes a function of the ramp gradient. For any speed, the maximum permissible acceleration the following equation [6], :

$$A = \frac{Q}{J} \qquad (1)$$

Where A is the acceleration, Q is the motor torque, and J is moment of Inertia. The time (T) taken to accelerate to the maximum speed (v) is:

$$T = v / A \qquad (2)$$

For linear profile, the acceleration velocity is constant and limit by the maximum permissible acceleration. In general, the motor is able to decelerate faster than it can accelerate. Therefore, If a single ramp used to control both acceleration and deceleration, the deceleration rate must be matched to the acceleration rate to prevent the damage may be happen to blood cells during acceleration

/deceleration process time, therefore the speed of acceleration and deceleration must be identical to produce smooth sedimentation for liquid contents.. The centrifuge controller will program according to ramp speed profile in which the distance and time of acceleration and deceleration are same. [7],[8], [9]

In practice, acceleration and deceleration period for centrifuge velocity is 16 second. In this research the laboratory centrifuge device type Kubota corporation model 2420, was used which the normal operation mode was selected to enable the device spin at 3000 rpm, with ramp speed profile that it's acceleration/deceleration have each 16 second time period.

Therefore, summation of constant velocity period (t_c), acceleration period (t_{Acc}), and deceleration period (t_{Dec}) are total period of linear velocity profile (T) as shown in figure 3a.

$$T = t_c + t_{Acc} + t_{Dec} \quad (3)$$

3. Experimental Setup

The Mathematical Model of the shorter separation process time and the separation efficiency greater than 95% of 0.35ml plasma, evaluated based on the mathematical model of ultrasound attenuation measurements in previous research [1]. Utilize of attenuation measurements of wave propagate through a sample of blood during centrifugation process, is to calculate the separation efficiency of blood-plasma. In this research we divided the mathematical model into two models, first is the time duration of centrifugation as a function of separation efficiency model, while the second model is device power consumption as a function of time duration centrifugation technique.

The tools used in the experimental setup, as shown schematically in figure 1, consisted of a blood tube, the ultrasound pulser, Gampt–Echo Scan as a receiver, switch, and software analysis, while figure 4 shows the experimental procedure steps for evaluate the mathematical model. The transducer with center frequencies of 2 MHz was attached to the outside of the vessel. In the attenuation measurements reported here, data was obtained for the 2 MHz transducer, which gave the required detection depth and sufficient level of clarity of the separation efficiency measurements of the blood plasma. Table 1 was filled follow same procedure mentioned in our previous research for evaluating the optimization time for centrifugation process. Therefore the two part of mathematical model can be derived.

Table 1. Evaluation of the attenuation, separation efficiency, and power consumption for discrete five minute using 180 watt centrifuge device.

Number of Operation	Constant speed period (minute)	Total spinning period (minute)	Attenuation dB/cm	Plasma separation efficiency %	Power Consumption kW.h
1	0.5	1.033	-0.0257	20	0.003099
1	1	1.533	-0.0662	35	0.004599
1	1.5	2.033	-0.1202	55	0.006099
1	2	2.533	-0.1607	70	0.007599
1	2.5	3.033	-0.2012	85	0.009099
1	3	3.533	-0.2282	95	0.010599

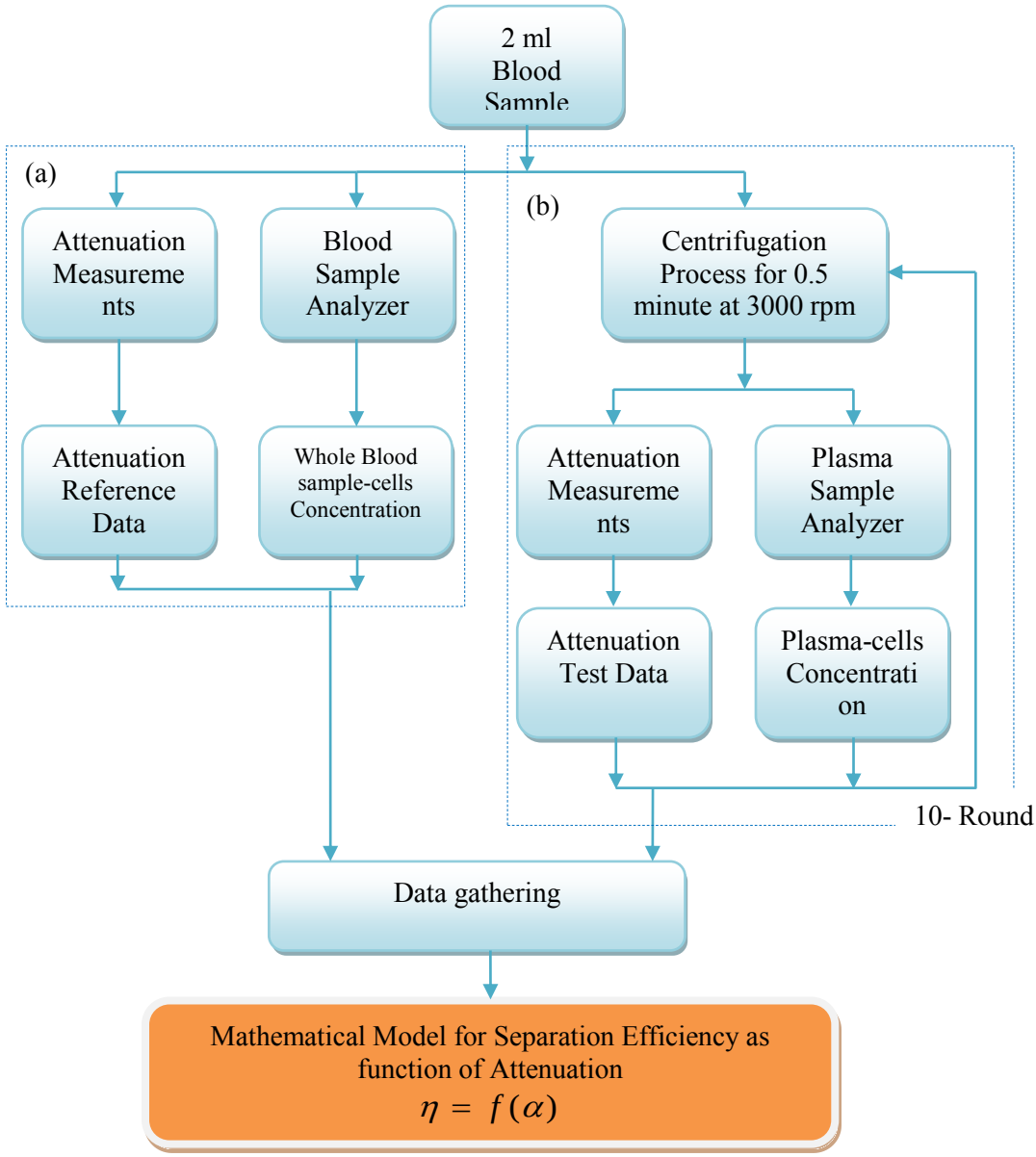


Fig.4. Experimental procedure sequence for one blood sample test.

Table 2 Monthly Electrical power Consumption for 180 watt centrifuge device.

Method Type	Plasma Separation Efficiency	Total spinning time $t_c + 2T_{Acc}$	Pc* for 100 time operating device daily kW.h	Monthly Pc* kW.h.
Currently	100%	5+2*16	1.659	49.77
Optimization time	95-100%	3+2*16	1.06	31.797

Pc* is power consumption.

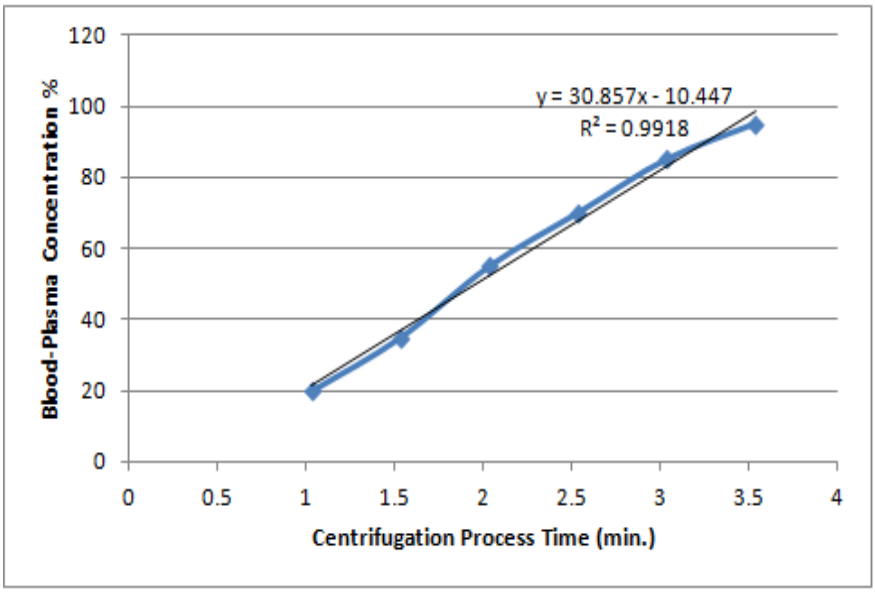


Figure 5. Blood-plasma concentration versus centrifugation time.

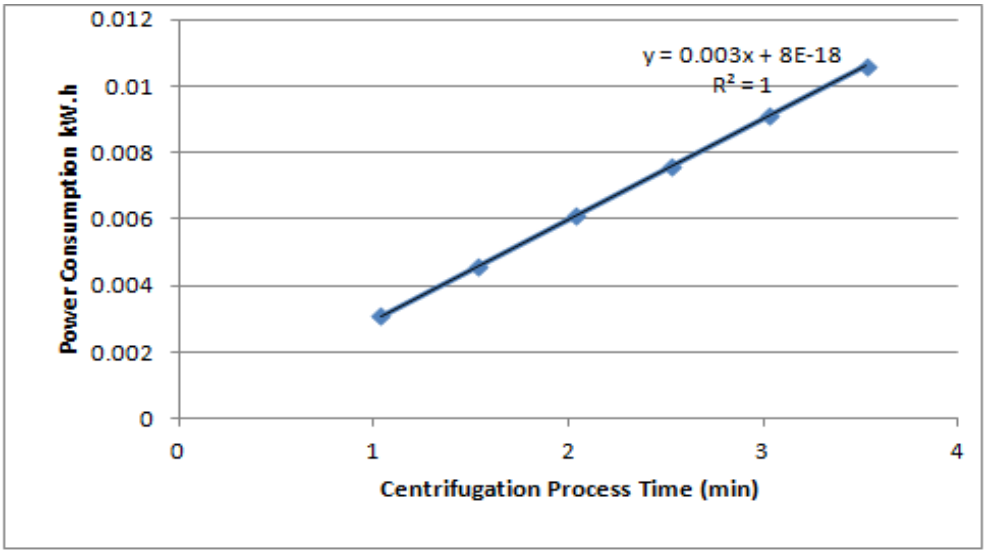


Figure 6. Power consumption versus 1ml blood sample centrifugation time.

3.1 *Centrifugation period model*

A mathematical relationship for the constant speed profile period (*tc*) as a function of separation efficiency (Π) was derive, table 1.

$$t_c = 0.0531\eta + 0.0155 \quad (4)$$

Linear speed profile was use to control the spinning of centrifuge device The rapid mode (linear speed profile) in which acceleration and deceleration period are match and equal to 16 second.

Therefore, the total period for centrifugation process be

$$T = (0.0531\eta + 0.0155) + t_{Acc} + t_{Dec} \quad (5)$$

According to prescribed separation efficiency only the time of constant speed change figure 3b. Based on experimental results, 0.35ml with greater than 90% plasma concentration, the proper time is 3 minute, therefore, the total time of centrifugation be about 3.5 minutes.

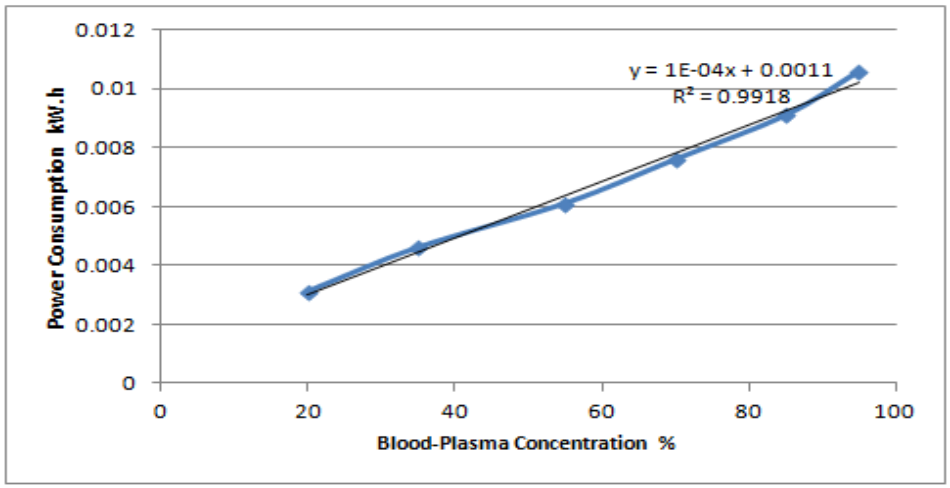


Figure 7. Centrifuge device power consumption measurements for (20-100)% Blood–plasma concentration.

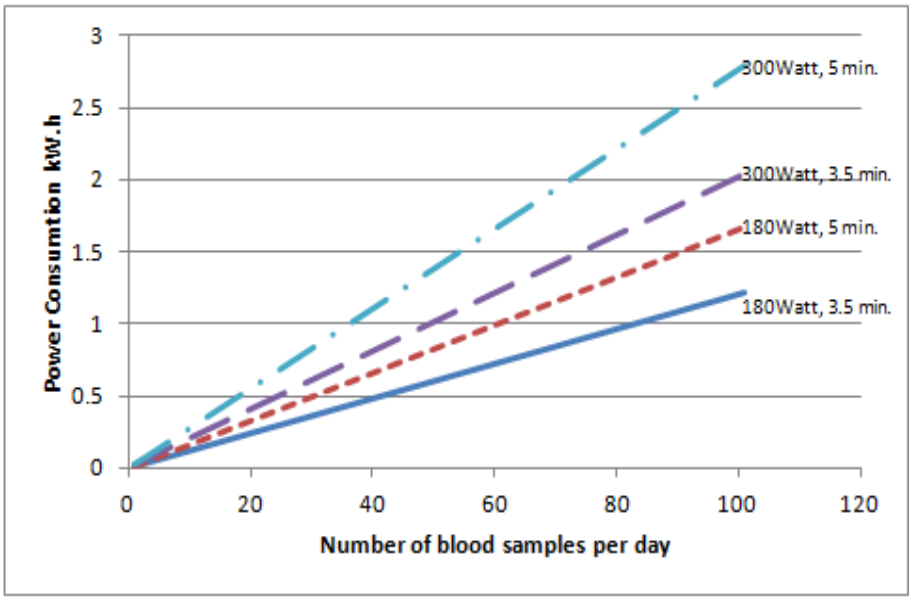


Figure 8. Power consumption measurements results for daily device operating using currently and optimize procedure of 180watt and 300watt laboratory centrifuge devices.

3.2 Power Consumption model

Electrical power consumption can be easily calculated using the following formula:

$$T_{PC}(kW.h) = D_{PC}(kW) \times O_t(h) \quad (6)$$

Where T_{PC} is the total power consumption, D_{PC} is device power consumption, and O_t is operation time period. The power consumption of Laboratory centrifuge device (Kubota corporation model 2420) used is 180watt [10]. The currently spinning time required to 0.35 ml plasma from 1 ml blood with separation efficiency greater than 90% , is five minute according to manufacture recommended, while based on proposed method (Attenuation measurements) is 3.5 minute, figure 5.

Therefore, the power consumption of currently centrifuge controller in which greater than 95% separation effieciny is 0.01659 kW.h (5 minutes sample pinning), while 0.0106 kW.h when using derived model (3.533 minute) ,figure 6, 7. Table 2 shows that about 18kW.h per month can be save using optimization time model. Figure 8 illustrates the comparison of the two different wattage centrifuges devices, using currently and proposed velocity profile.

Conclusion

The mathematical model of optimization time of centrifugation process is included the acceleration and deceleration period, because of , the blood sample subjected to accelerated centrifugal force during acceleration period, same thing for deceleration period. These forces are contributes the main centrifugal force (at 3000 rpm) to precipitation of blood cells from plasma. Based on the derived model, the currently centrifuge controller can be modified by reprogram it with equation (5). This low cost modification leads to decrease time duration of blood test, and device power consumption, keeping separation efficiency same as currently procedure. In addition, Equation (5) increases the reliability for centrifuge device to estimate the centrifugation period for predefined separation efficiency figure 4. The relationship between device power consumption and centrifugation time and plasma separation efficiency is linear as shown in figure 4 and 5 respectively, therefore, the power consumption for any centrifuge device wattage can be estimate. The mathematical model derived based on attenuation measurements has successfully save the power consumption of centrifugation process. 18kW.h monthly for 100 daily time device operation had been saved using the proposed model. Figure 7 shows that a comparison for power consumption using currently and modified controller of centrifuge device.

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