A NOVEL HUMAN BLOOD-PLASMA SEPARATION EFFICIENCY MEASUREMENT METHOD BASED ON ULTRASONIC TECHNIQUE

by

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DEDICATION

To the Spirit of the Martyr

Dr. Safaa Sabri Salim

&

To My

Parents

Sisters & Brothers

Wife & Sons

Nephews

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LIST OF ABBREVIATIONS

AITF	Acoustic impedance transfer function of liquid under centrifuging process.
AOD	Acousto-Optic Deflector
BLDC	Brush Less Direct Current motor
CE	Change of Error
DC	Direct current
DEP	Dielectrophoresis
E	Error
EAM	Electro Acoustic Measurement model
EDTA	Ethylene Diamine Tetra Acetic Acid
EMF	Electromagnetic Field
FB	Buoyancy Force
FC	The centrifugal force
FD	The Viscous Drag Of Force
FFT	Fast Fourier transform
FG	The Force of Gravity
FLC	Fuzzy Logic Control
HCT	Hematocrit
I/O	Input / Output
IGBT	Insulated-gate bipolar transistor
IS	Signal of interest
LCD	Liquid Crystal Display
LTI	Linear time-shift invariant system

MACS	Magnetic activated cell sorting
MOSFET	Metal–oxide–semiconductor field-effect transistor
NDE	Non Destructive Evaluation
NL	Negative Large
NM	Negative Medium
NS	Negative small
pDEP	positive dielectrophoresis
pH	The measurement of the hydrogen ion concentration.
PID	Proportional Integral Derivative control
PL	Positive Large
PLT	Thrombocytes
PM	Positive Medium
PMMA	Polymethylmethacrylate
PPD	Power-pulse decay ultrasonic pulser
PS	Positive Small
PWM	Pulse Width Modulation
RBC	Red Blood Cell
RCF	Relative Centrifugal Force
rpm	Revolution per minute
SE	Separation Efficiency
USW	Ultrasonic wave
WBC	White Blood Cell
ZE	Neutral

LIST OF SYMBOLS

C_B	Sound speed in human blood (m/sec.)
C_P	Sound speed in human blood-plasma (m/sec.)
V_{Bm}	The FFT amplitude for echo *m*, for blood
V_{Pm}	The FFT amplitude for echo *m*, for plasma
f_p	The reduction factor of signal amplitude propagated through plasma
f_B	The reduction factor of signal amplitude propagated through blood
V_m	The amplitude of transmitted pulse (volt)
V_o	Initial amplitude of transmitted pulse
K_P	The constant is include the transmission and reflection coefficients at the interfaces and the beam diffraction
K_B	The constant is include the transmission and reflection coefficients at the interfaces and the beam diffraction
t_c	Constant speed Period (minute)
t_{Acc}	Acceleration speed period (minute)
t_{Dec}	Deceleration speed period (minute)
T	Total time for separation efficiency (minute)
α_i	Weighing factor
R_c	Mamdani's minimum operation (FLC)
T_{PC}	The total power consumption (KWatt.hour)
D_{PC}	Device power consumption (Watt)

O_t	Operation time period (hours)
F_B	The blocked force (Kg)
v_T	terminal velocity
$\mathrm{Z_t}$	acoustic radiation impedance of the transmitter
A_i	Incident amplitude wave
A_r	Reflected amplitude wave
A_t	Transmitting amplitude wave
F_B	Acoustic input force to receiver
F_i	Acoustic pulser output force
F_{inc}	The force of the wave's incident on the area of the receiver
J_1	Bessel functions of order one
J_o	Bessel functions of order zero
S_e	Separation efficiency
S_{vl}^A	Sensitivity of transducer
S_{vl}^B	Sensitivity of receiving transducer
V_R	Output voltage of acoustic receiver
$V_i(\omega)$	Thevenin equivalent voltage of the pulser
Z_i^e	Electrical input impedance for ultrasonic pulser
Z_{in}^{Ae}	Electrical impedance of transducer
Z_{in}^{Be}	Electrical impedance of receiving transducer
Z_o^e	Electrical impedance of ultrasonic receiver
t_A	Transfer function of medium
t_G	Transfer function of ultrasound transmitter (pulser)
t_R	Transfer function of acoustic receiver (second)

v_o	velocity on the face of the transmitting transducer
w_l	The maximum safely spinning operation (rpm)
α_w	Attenuation coefficient of water (dB)
ρ_o	Maximum allowed density of the fluid sample (Kg/m³)
ρ_p	Density of blood-plasma
ρ_s	density of solution
ω_o	Maximum angular velocity that the centrifuge can operate
a	Radius of transmitter transducer (mm)
b	Radius of receiver transducer (mm)
B	Friction Coefficient
c	Speed of sound (m/s)
D	Distance between two transducers (cm)
E	Energy (Joul)
e_x	Unit vector in the x-orinttion
f	Frequency (Hz)
g	Earth Gravity (Kg.m/sec.)
J	Moment of inertia (Kg.m²)
ke	Voltage constant
kt	Torque constant (N.m)
l	the depth of fluid (cm)
L	Stator equivalent inductance (Henry)
m	Mass (Kg)
m	The pulse number sent
η	Viscosity (Pa.s, Kg/(s.m))
P	Number of motor pole

r	Radius (m)
R	centrifuge rotor (cm)
s	The slope of natural logarithm
T	Transmitting coefficient
t	Centrifugation period (minute)
τ_{xx}	Stress of p-wave
u_x	Displacement of p-wave
v	Volume (m^3)
v	linear velocity (m/s)
v_x	Velocity of p-wave
w	Vessel wall thickness (mm)
X_B	The distance travelled in the blood
X_p	The distance travelled in the plasma
X_{poly}	The distance travelled in the polyethylene
X_w	The distance travelled in the water
z	Acoustic impedances
z_1	Acoustic impedance of first medium
z_2	Acoustic impedance of second medium
Z_B	Acoustic Impedance of blood
Z_p	Acoustic Impedance of plasma
Zpoly	Acoustic Impedance of polyethylene
Z_w	Acoustic Impedance of water.
ρ	Density (Kg/m)
R	Reflection coefficient
$S(\omega)$	Ultrasonic measurement function system

α	Attenuation coefficient (dB)
θ	rotational angle (radian)
ω	Angular velocity

Kecekapan Pemisahan Blood-Plasma Manusia Novel Langkah Pengukuran Berdasarkan Teknik Ultrasonik

ABSTRAK

Diagnosis penyakit klinikal berganting leaped kesimpulan-kesimpulan awal disediakan oleh ujian darah. Diagnosis penyakit tepat menjadi contoh kepentingan genting pemisahan sesuai plasma darah, yang mengandungi antibodi dan protein, dari platelet dan merah dan sel darah putih sebelum ujian. Kaedah paling biasa darah klinikal pemisahan melalui pengemparan, berdasarkan teori pemendapan. Ketidaktepatan pemisahan plasma darah berlaku bukan sahaja kerana sel berbeza dari satu orang kepada yang lain dalam saiz dan ketumpatan mereka tetapi juga disebabkan variasi dalam umur manusia, persekitaran selular dan teknik ukuran. Sebagai tambahan, kadar mendapan terjejas oleh perubahan di kelikatan dan ketumpatan sampel, yang boleh membawa kepada pemisahan tidak lengkap. Dalam disertasi ini, kecekapan pemisahan peranti emparan makmal ditingkatkan dengan menggabungkan teori akustik dengan teori pemendapan. Kelakuan gelombang membiakkan melalui cecair semasa pengemparan dikaji , dan fungsi pindah akustik model diterbitkan. Fungsi pindah akustik terbitan memudahkan proses penilaian prestasi sistem berdasarkan satu ujian luar talian bagaimana perubahan dalam impedans akustik menjejaskan satu penyelesaian. Penilaian ini akan membantu untuk mengelak kajian pengesahan percubaan mahal. Kepekatan yang rendah sel-sel darah digantung dalam sampel-sampel plasma telah dikesan dan mengukur melalui teknik denyut gelombang ultrasonik baru memanggil Power-Pulser Decay (PPD). PPD menghasilkan nadi pelbagai reput yang disuntik dalam sampel darah untuk proses pengemparan diskret menghasilkan keupayaan pengesanan untuk kepekatan yang rendah zarah dalam cecair. Hasilnya, satu model matematik baru untuk kecekapan pemisahan diterbitkan. Sebegini model berdasarkan kepada kerja eksperimen dan menentu masa pemisahan halaju pemintalan bekerja malar, yang menyebabkan dalam masa pemisahan dioptimumkan untuk satu input ditakrifkan kecekapan pemisahan. Berdasarkan keputusan-keputusan ini, pengawal pengemparan baru direka bentuk , dan prestasinya disimulasikan. Keputusan masa pengemparan model menunjukkan bahawa pengemparan selama 3 minit di 3000 rpm untuk satu jilid 0.35 ml mencukupi pada hasil plasma dengan kecekapan pemisahan lebih besar daripada 95%. Jumlah 0.35 ml telah terpilih kerana jumlah ini mencukupi untuk jenis penyakit berbilang ujian. Dalam disertasi ini, pengawal emparan baru direka berdasarkan satu Fuzzy Logic Controller. Masa pengoptimuman model mendedahkan bahawa pengawal ini menyelamatkan kira-kira 2 minit dengan lebih banyak daripada 95% kecekapan pemisahan dibandingkan dengan emparan semasa pengawal. Emparan baru pengawal membenarkan pemisahan boleh laras ketepatan, masa pemisahan lebih pendek dan penggunaan kuasa rendah dalam perbandingan dengan emparan klasik peranti. Pengawal akan berjaya menjimatkan 18kW.h bulanan kerana menganggap bahawa emparan dikendalikan 100 kali setiap hari. Kecekapan pemisahan lebih baik akan membawa kepada peningkatan-peningkatan luas dalam proses pengemparan, termasuk keupayaan mentakrifkan peratusan pemisahan dan ketepatan pemisahan untuk kandungan satu penyelesaian. Dalam penggunaan perubatan, teknik ini akan mengakibatkan lebih keputusan-keputusan ujian yang tepat yang boleh.

A Novel Human Blood-Plasma Separation Efficiency Measurement Method Based on Ultrasonic Technique

ABSTRACT

Clinical diagnosis of disease relies on the preliminary conclusions provided by blood testing. Accurate disease diagnosis exemplifies the crucial importance of proper separation of the blood plasma, which contains antibodies and proteins, from the platelets and red and white blood cells before testing. The most common method of clinical blood separation is via centrifugation, based on sedimentation theory. Inaccuracy of blood-plasma separation occurs not only because cells vary from one person to another in their size and density but also due to variations in the human age, cellular environment and measurement technique. In addition, the sedimentation rate is affected by changes in the viscosity and density of the sample, which can lead to incomplete separation. The separation efficiency of a laboratory centrifuge device is enhanced by combining acoustic theory with sedimentation theory. The behaviour of waves propagating through a liquid during centrifugation is studied, and the acoustic transfer function model is derived. The derived acoustic transfer function facilitates the process of system performance assessment based on an off-line test of how changes in acoustic impedance affect a solution. This assessment will help to avoid costly experimental validation studies. Low concentrations of blood cells suspended in plasma samples were detected and measured via a new ultrasound pulse technique called Power-Pulser Decay (PPD). The PPD generates multi-decay pulses that are injected into the blood sample for a discrete centrifugation process to yield the detection ability for low concentrations of particles in a liquid. As a result, a new mathematical model for the separation efficiency is derived. This model is based on experimental work and defines the separation time of a constant working spinning velocity, which results in an optimised separation time for a predefined input of the separation efficiency. Based on these results, a new centrifugation controller is designed, and its performance is simulated. The results of the centrifugation time model demonstrate that centrifugation for 3 minutes at 3000 rpm for a 0.35-ml volume is sufficient to produce plasma with separation efficiency range of (95-100)%. The volume of 0.35 ml of 1ml blood sample was selected because this volume is sufficient for multiple types of disease tests. New centrifuge controller is designed based on a Fuzzy Logic Controller. The optimisation time model reveals that this controller saves approximately 2 minutes with 95% separation efficiency compared with the PID centrifuge controller. The new centrifuge controller allows for adjustable separation accuracy, a shorter separation time and low power consumption in comparison with the commercial centrifuge device. The controller successfully saves 18kWh monthly for assuming that the centrifuge is operated 100 times per day. The improved separation efficiency will lead to broad improvements in the centrifugation process, including the ability to define the percentage of separation and the separation accuracy for the contents of a solution. In medical applications, this technique will result in more accurate test results that can be obtained more quickly, which will improve the ability of physicians and patients to make important clinical decisions.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Every reason for separating blood can be reduced to the universal desire to continue living. Effective methods for isolating, concentrating, and accumulating one or more components of blood can advance our ability to understand the characteristics of blood, to achieve the state of an individual's health, and to treat diseases of the body. The three basic reasons for separating blood are scientific knowledge, therapeutic treatment and diagnostic testing (Roche, 2001).

Clinical diagnoses rely heavily on the preparatory findings of blood tests. Point-of-care testing is usually not included in blood tests. Refining blood plasma and carrying out complete tests using sample volumes of at least 3 ml can take hours or days. Identifying disease tags, cholesterol levels, organ function, infection, or blood types are common purposes for blood tests (Delinder and Groisman, 2006).

Accurate disease testing demonstrates the importance of correct separation by requiring that the blood plasma, complete with proteins and antibodies, be isolated from the red, white and platelet blood cells before testing. The most common method of clinical blood separation is centrifugation. This process, however, is both time and space consuming in terms of the amount and size of equipment needed and the amount of time needed to gain accurate results (Hinkle, 2008).