بسم الله الرحمن الرحيم

Electrical Engineering Department

Biomedical Engineering

Graduation Project

A Real Time Ionic Dialysance Monitoring By Using Conductivity Cell

Project Team

Ala'a Zama'reh **Musab Alnajjar**

Project Supervisor

Eng.Fidaa Jaafrah

Hebron – Palestine

May, 2014

Abstract

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By the Guidance Of Our supervisor, and by all members in the testing committee, this project delivered to department of electrical engineering in the college of engineering and technology ,to be as a partial Fulfillment of the requirement of the department for the degree of B.Sc

Supervisor Signature

Testing Committee Signature

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Chief of the Department Signature

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First and for most we should offer our thanks , obedience and gratitude to Allah .

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Abstract

During dialysis treatments, there is an interest of measuring the dialysis efficiency for each treatment. An easy method has been developed and is based on measuring the outlet conductivity of the dialysis fluid. The conductivity measuring continuously along dialysis session every 30 minutes.

The project made for Fresenius Hemodialysis machine model (model 4008B).And 4-poles conductivity cell is used in the project, because it has high accuracy. And AC constant current is applied to it.

Abbreviations

A - Absorbance

ACR - Acute Renal Failure

C - Concentration

CRF - Chronic Renal Failure

DAQ – Data acquisition system

ESRD - End Stage Renal Failure

HD - Hemodialysis

ID - Ionic Dialysance

k – Clearance

kt/V - dialysis dose (adecuacy)

M - trans-membrane flux),

OCM - On-line Clearance Monitor from Fresenius medical care.

PVC - Polyvinyl chloride

RF - Renal Failure

RO - Reverse Osmosis

t – Stands for time

UF- Ultra-filtration

UM - Urea Monitor 1000, from Baxter Healthcare Corp.

URR - urea reduction ratio

US - Ultrasound

V - Stands fir total body water

Chapter one

Introduction

1.1 Overview.

1.2 Project Objectives.

1.3 Literature Review.

1.4 Time Plan.

1.5 Project Cost.

1.6 The Contents of Chapters

Chapter one

Introduction

1.1 **Overview.**

1.2 **Project Objectives.**

1.3 **Literature Review.**

1.4 **Time Plan.**

1.5 **Project Cost.**

1.6 **The Contents of Chapters**

1.1 Project Overview

Renal failure is a condition where the kidney function is inadequate. As the renal function deteriorates, disorders will rapidly develop in most of the major body organs and internal systems; a syndrome commonly known as uremia. When suffering from uremia, many of the waste products from the metabolism accumulates in the body. Concentration levels of substances like urea (major component in urine) and creatinine (break-down product in skeletal muscles) increases in the blood, as well as the amount of water in the body, since excretion is reduced.

If not subjected to kidney transplantation, all patients with severe renal failure receive dialysis treatment when the kidney function is reduced to 10% or less of a normal kidney. In general, dialysis is a method to clean the blood from toxic metabolites and acids. It also removes and restores excess water and electrolyte imbalances.

Despite the fact that removal of larger molecular weight uremic toxins are very important for the long-term outcome in chronic dialysis, the most widely used dose parameter in dialysis is based on small solute removal. The dose parameter, is a measure of how effective a dialysis treatment is, and among the small solutes, urea clearance (K) is the most common efficiency parameter. Multiplying K with the treatment time (t) and normalizing it to body size with the urea distribution volume (V), gives the normalized dialysis dose Kt/V. Although the validity of Kt/V is not without controversy, it is today recognized as an important quality control parameter in chronic dialysis.

During treatments, there is an interest of measuring the dose of dialysis. One common way of doing this is to look at how much urea that has been removed from the patients body during the full treatment.

This method however, is normally time-consuming since it involves taking blood samples from the patient and needs to be sent for laboratory analysis. Another method using ammonium ion sensor that measures the amount of ammonium ion (NH_4^+) determined directly by an ion-specific electrode, this method need extra work. A much easier method has been developed and is based on measuring the conductivity of the dialysis fluid, or with other words, the ability of the dialysis fluid to conduct electric current

1.2 Project objectives

The main objective:

3) Continuous measurement of the hemodialyzer outlet conductivity, when the inlet conductivity is changed for about 0.6mS/cm during 4 minutes.

2) Calculate the depurated volume ($ID*t$) and dialysis adequacy ($ID*t/v$) by Lab VIEW.

1.3 Literature Review

There are three previous methods for calculating urea:

[1] **Blood Sample**: The k*t/V value is usually calculated from blood urea measurements before and after dialysis. However, the drawback concerning this procedure is that it requires blood samplings, and urea concentration measurements. The results are not immediately available because the samples must be sent for laboratory analysis, which means additional treatment costs. The accuracy of the results also depends on precise sampling timing, thus, the blood based urea k*t/V is not a very practical quality control tool for each dialysis treatment.

[2] **Enzymatic sensor:** method for continuous ammonium-selective enzymatic monitoring of the artificial kidney by means of a bioelectrochemical urea electrode. The urea is converted in an enzyme membrane by covalently bound urease and the ammonium ions are detected by a Nonactin-PVC-membrane. The technique is designed to measure urea concentration on-line in the effluent dialysate stream.

A membrane with the enzyme urease is the catalyst to the chemical reaction when it comes in contact with urea in the spent dialysate.

1.4 Time Schedule

The time plan, represents the main stages of the establishing the project, is divided into the two semesters as shown in the following tables.

The Table 1.1 shows the activities that done in the project First semesters, and the time of each one.

Table 1.1: Table for First the semester

Weeks / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System Definition	■	■	■	■												
System Analysis					■	■	■	■								
System Design									■	■	■	■	■			
Presentation Preparing														■	■	■
Documentation				■	■	■	■	■	■	■	■	■	■	■		

The following table defines the main tasks in the project:

Table 1.2 Time Table for the Second Semester

Weeks / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Collection data																
Design																
Analysis																
Building and testing system																
Documentation																
Preparing presentation																

1.5 Project Cost

Table 1.3: Project Cost

Component	Cost $
Conductivity cell	100 $
Equipments & tools (op-amps , resistors, capacitors. ...	200 $
Programming & DAQ	100 $
Total	400 $

1.6 The Contents of Chapters

Chapter Two: physiological back ground for kidney structure and hemodialysis machine. In this chapter we will focus on the kidney, its failure and complications (Uremia) and treatment (HD machine). And it also discusses why urea used as a marker.

Chapter Three: previous methods for calculating dialysis adequacy in addition to a new method (by conductivity cell). There are two methods for determining dialysis adequacy, Blood sample & urea monitoring by using enzymatic sensor.

Chapter Four: contains HD block diagram, general block diagram for project, and wien bridge oscillator, constant current source circuits , project circuit & the calculations for circuits.

Chapter Five: contains Lab VIEW front panel, equations for determining dialysis adequacy, and general flow chart for project.

Chapter six: contains the result of the project, recommendation, challenges and future works. The results for AC & DC currents and for 3-poles &4-poles conductivity cells.

Chapter Two

Physiology Background

2.1 Introduction

The urinary system, also known as the renal system, consists: **Two kidneys,** two ureters, the bladder, and Urethra. In this chapter we will focus on the kidney, its failure and complications (Uremia) and treatment (HD machine). And it also discusses why urea used as a marker.

2.2 The Kidneys Structure

The kidneys are bean-shaped organs, each about the size of a fist. They are located near the middle of the back, just below the rib cage, one on each side of the spine. The kidneys are sophisticated reprocessing machines. Every day, a person's kidneys process about 200 quarts of blood to sift out about 2 quarts of waste products and extra water. The wastes and extra water become urine, which flows to the bladder through tubes called ureters. The bladder stores urine until releasing it through urination.

Each kidney is surrounded by membrane know as the renal capsule, each kidney is made up of approximately a million nephrons, each nephron consists of a filtering component called glomerulus and a tubule reabsorbs essential water and chemicals into the blood stream and transports urine from the glomerulus to the ureters.

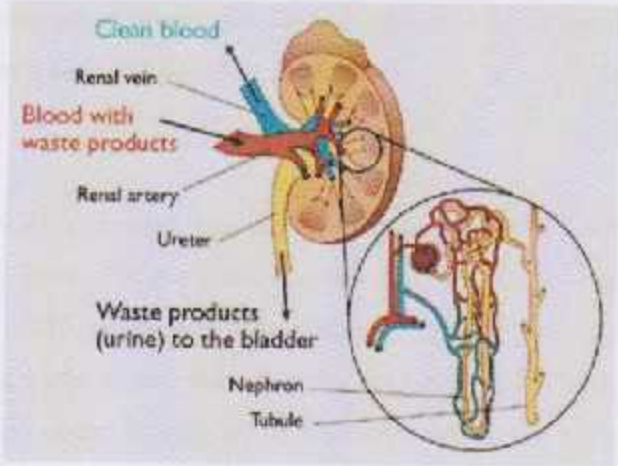


Figure 2.1: Human Kidney and Nephron

The kidneys perform a number of important functions. They are [1]:

1) Remove waste products from the body.

2) Control the amount of fluid in the body.

3) Control the chemical composition of the body.

4) Produce certain important hormones and chemicals.

2.3 Renal failure

Renal failure is a condition where the kidney function is inadequate. As the renal function deteriorates, disorders will rapidly develop in most of the major body organs and internal systems; a syndrome commonly known as uremia. When suffering from uremia, many of the waste products from the metabolism accumulates in the body. Concentration levels of substances like urea (major component in urine) and creatinine (break-down product in skeletal muscles) increases in the blood, as well as the amount of water in the body, since excretion is reduced.

Common physical symptoms of uremia are fatigue, nausea, loss of appetite, skin itching and if left untreated, uremia will eventually lead to death.

Renal Failure (RF) is divided into acute renal failure (ARF) and chronic renal failure (CRF). ARF is an acute damage of the kidney tissues often reversible or partly reversible, caused by hypoxic, toxins etc. CRF is the slow loss of kidney function over time. (CRF) slowly gets worse over time. In the early stages, there may be no symptoms. The loss of function usually takes months or years to occur. It may be so slow that symptoms do not appear until kidney function is less than 10% of normal.

The final stage of (CRF) is called end-stage renal disease (ESRD). At this stage, the kidneys are no longer able to remove enough wastes and excess fluids from the body. The patient needs dialysis or a kidney transplant [2].

2.4 Renal Failure Reasons

Most kidney diseases attack the nephrons, altering their ability to filter blood and produce urine. Renal failure occurs from a variety of causes, and the time course and clinical symptoms vary from individual to individual. A person's kidney failure may occur suddenly or progress slowly over a period of many years. As failure progresses the kidney is less able to maintain a steady volume and concentration of body fluids. For many, as fluid and salt become increasingly difficult to remove, high blood pressure occurs as well as edema or fluid in the tissues. Patients may have problems with swelling of their legs and shortness of breath from accumulation of fluid in the lungs (pulmonary edema). Medications may be necessary to control blood pressure and assist in fluid removal (diuretics). The kidneys also are no longer able to excrete the waste products of metabolism, and substances such as potassium and phosphorus can accumulate in the body. Elevated phosphorus levels cause calcium levels in the blood to fall and result in the stimulation of a hormone from the parathyroid glands. This hormone increases the release of

calcium from bones and if not suppressed can result in bone pain and progress to weakened bones. The most common causes of kidney disease are: Diabetes, high blood pressure, poisons, certain drugs, cardiovascular disease (ischemic heart disease, chronic heart failure, peripheral vascular disease and cerebral vascular disease), structural renal tract disease, renal calculi or prostatic hypertrophy and cancer [3].

In HD machine, there are two basic parts that simulate the natural organs in the human body, the blood pump or peristaltic pump simulate the heart pump, it is used to pull blood from the artery. The second part is dialyzer that performs filtering operation which simulates the nephrons in natural kidney [4].

If we make comparison between natural kidney and the artificial kidney, we find the following differences in Table 2.1:

Table 2.1: Natural Kidney vs. Artificial Kidney

	Natural Kidney	Artificial Kidney
Pump	Heart	Blood pump
Filter	Nephrons	Dialyzer
Weights	30 grams	110 killograms
Number of filters	One million nephrons per kidney	12000-17000 fiber
Number of dialysis	36 per day	3 per week

In Fig 2.2 shows how the HD works and its components, will be explained later.

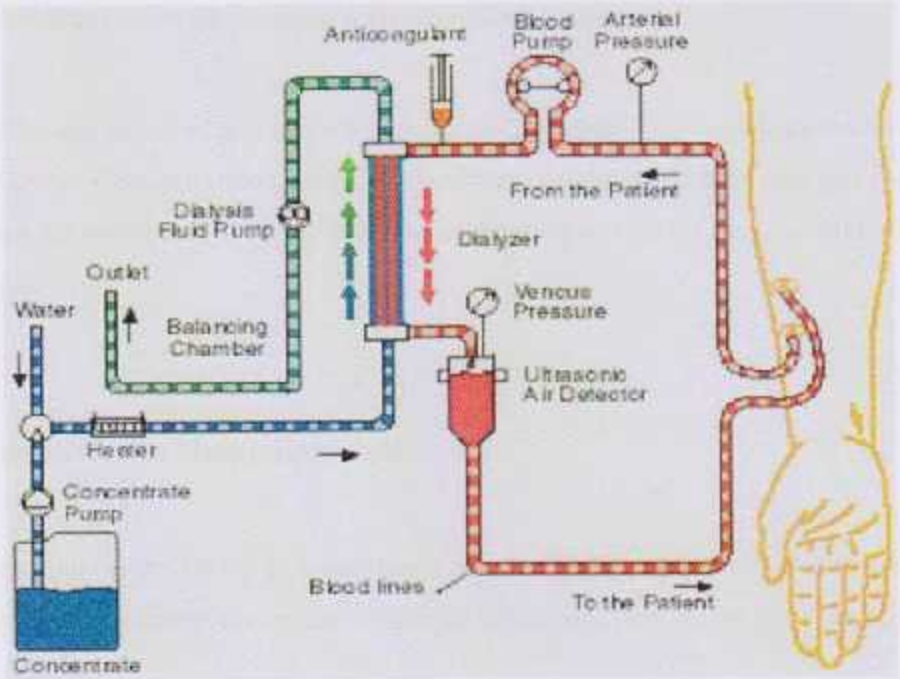


Figure 2.2: HD work and component

2.5.1 Molecular Transport Mechanism:

There are three different types of physical transport mechanism behind dialysis: diffusion, Osmosis and Ultrafiltration (convection).

- **Diffusion:** The movement of solutes from higher to lower solutes concentration (very efficient for removing small molecules).
- **Osmosis:** The movement of water through a membrane from a higher to a lower concentration area.

- **Ultra-filtration (UF):** The movement of fluid across a membrane caused by a pressure gradient.
- **Convection:** The movement of solutes with a water flow, "solvent drag", e.g. movement of membrane permeable solutes with ultra-filtered water.

By diffusion, osmosis, and UF, water and metabolites are exchange between blood and the dialysate solution. Concentration gradients cause waste products, such as urea and creatinine, to diffuse across the membrane from the blood to dialysate. Electrolytes move in both directions to maintain equilibrium.

2.6 Conductivity in Hemodialysis machine

Conductivity is the ability of a solution, a metal or a gas - in brief all materials - to pass an electric current. In solutions the current is carried by cations and anions whereas in metals it is carried by electrons.

How well a solution conducts electricity depends on a number of factors:

- Concentration
- Mobility of ions
- Valence of ions
- Temperature

All substances possess some degree of conductivity. In aqueous solutions the level of ionic strength varies from the low conductivity of ultra pure water to the high conductivity of concentrated chemical samples[5].

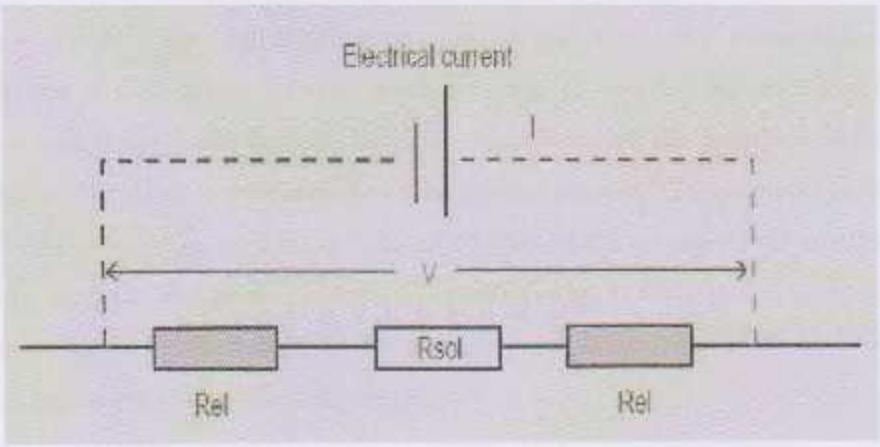
2.6.1 Types of Conductivity Cell

There are three types of conductivity cell: 2-pole, 3-pole and 4-pole cell.

1) 2-Pole Cell

In a traditional 2-pole cell, an alternating current is applied between the 2 poles and the resulting voltage is measured. The aim is to measure the solution resistance (R_{sol}) only. However the resistance (R_{el}) caused by polarization of the electrodes and the field effect interferes with the measurement, and both Rsol and Rel are measured.

(a)



(b)

Figure 2.3 : (a) 2-pole cell. (b) Simplified diagram of a 2-pole conductivity cell.

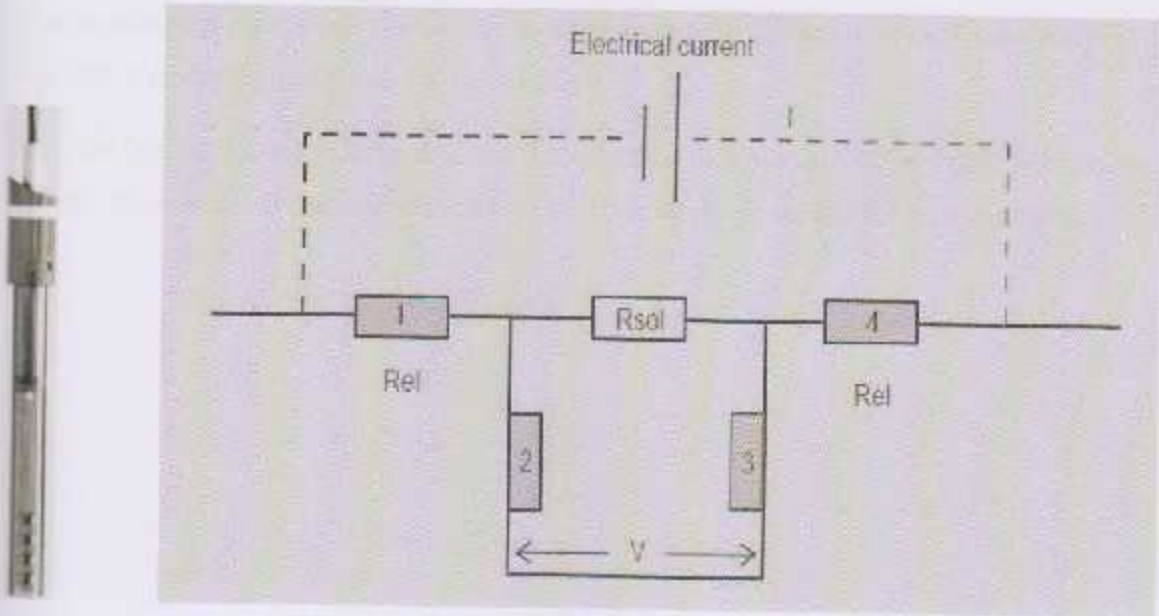
2) 3-Pole Cell

The 3-pole cell is not as popular now as it has been replaced by the 4-pole one. The advantage of this design was that the third pole which was linked to pole 1 allowed the field lines to be guided and confined in an optimal manner, limiting dispersion in the measurement and minimizing influences on the measurement such as beaker volume and position of the cell in the beaker (field effect). It guarantees a better reproducibility when determining the cell constant and therefore more reproducible results.

3) 4-pole cell

In a 4-pole cell, a current is applied to the outer rings (1 and 4) in such a way that a constant potential difference is maintained between the inner rings (2 and 3). As this voltage measurement takes place with a negligible current, these two electrodes are not polarised ($R_2 = R_3 = 0$). The conductivity will be directly proportional to the applied current. The geometry of 4-pole cells with an outer tube minimizes the beaker field effect, due to the measurement volume being well defined within the tube. The position of the conductivity cell in the measuring vessel or the sample volume therefore has no influence on the measurement. In our project we use this type of conductivity cell, because it has several advantages :

1) Linear over a very large conductivity range.
2) Calibration and measurement in different ranges changer.
3) Flow-through or immersion type cells
4) Ideal for high conductivity measurements
5) Can be used for low conductivity measurements



(a) (b)

Fig 2.4 : (a) 4-pole cell. (b) Simplified diagram of a 4-pole conductivity cell[5].

2.6.2 Dialysate and conductivity

The conductivity of the dialysate is mainly determined by its sodium content, which means that the calculated K value is mainly related to the transfer of sodium (ions) across the dialyzer membrane. Therefore, some refers K as ionic dialysance (*ID*) [5]. Sodium is very much alike urea regarding molecular weight, diffusive and convective behavior. Normally, concentration values are used to calculate *ID*. But it has been shown for urea that the concentration values can be approximated with conductivity values in dialysate, and that there is a very close agreement between the ionic dialysance and urea clearance [6].

By integrating the results over time, Diascan provides regular updates on the effective dialysis dose delivered during treatments, i.e. the Kt-value.

Since the Diascan feature is automated and does not lead to significant sodium gain or interfering with the solute transport process in the dialyzer, it can safely be applied for each treatment.

Chapter Three

Previous Method For Measuring Dialysis Adequacy

3.1 Introduction

3.2 Blood Sample

3.2.1 Urea Reduction Ratio (URR)

3.2.2 kt/v index

3.2.3 Drawbacks

3.3 Urea monitor by Using Enzymatic sensors

3.3.1 Drawbacks

3.4 Using Conductivity Sensor (ID)

3.4.1 How to Measure conductivity

3.4.2 How to Measure ID (Diascan)

3.1 Introduction

Adequacy of dialysis refers to how well we remove toxins and waste products from the patient's blood. But the Clinical Practice Guideline on Adequacy of Hemodialysis defined adequate hemodialysis as the recommended quantity of hemodialysis delivered which is required for adequate treatment of ESRD such that patients receive full benefit of hemodialysis therapy.

3.2 Blood Sample

To see whether dialysis is removing enough urea, the dialysis clinic should periodically-normally once a month-test a patient's blood to measure dialysis adequacy. Blood is sampled at the start of dialysis and at the end. The levels of urea in the two blood samples are then compared. Two methods are generally used to assess dialysis adequacy, *URR* and *Kt/V*.

3.2.1 Urea Reduction Ratio (URR)

URR stands for urea reduction ratio, meaning the reduction in urea as a result of dialysis. The URR is one measure of how effectively a dialysis treatment removed waste products from the body and is commonly expressed as a percentage.

Example: If the initial, or predialysis, urea level was 50 milligrams per deciliter (*mg/dL*) and the Postdialysis urea level was 15 *mg/dL*, the amount of urea removed was 35 *mg/dL*.

$$50\ mg/dL - 15\ mg/dL = 35\ mg/dL$$

The amount of urea removed (35 mg/dL) is expressed as a percentage of the Predialysis urea level (50 *mg/dL*).

$$35/50 = 70/100 = 70\%$$

Although no fixed percentage can be said to represent an adequate dialysis, patients generally live longer and have fewer hospitalizations if the URR is at least 60 percent. As a result, some experts recommend a minimum URR of 65 percent.

The URR is usually measured only once every 12 to 14 treatments, which is once a month. The URR may vary considerably from treatment to treatment. Therefore, a single value below 65 percent should not be of great concern, but a patient's average URR should exceed 65 percent.

3.2.2 kt/v index:

Kt/v is another way of measuring dialysis adequacy. In this measurement:

- *k*: stands for the dialyzer clearance, the rate at which blood passes through the dialyzer, expressed in milliliters per minute (ml/min).
- *t*: stands for time
- *V*: stands for total body water
- ***KT***, the top part of the fraction, is clearance multiplied by time, representing the volume of fluid completely cleared of urea during a single treatment.

Example: If the dialyzer's clearance is 300 mL/min and a dialysis session lasts for 180 minutes (3 hours), *Kt* will be 300 *mL/min* multiplied by 180 minutes. The result comes to 54,000 *mL*, or 54 liters.

Kt – 300 *mL/min* multiplied by 180 minutes

$Kt = 54{,}000\ mL$ – 54 liters

The body is about 60 percent water by weight. If a patient weighs 70 kilograms (kg), or 154 pounds (lbs), *V* will be 42 liters.

V = 70 *kg* multiplied by .60 = 42 liters

So the ratio-*K* multiplied by t to *V*, or *Kt/V*-compares the amount of fluid that passes through the dialyzer with the amount of fluid in the patient's body. The *Kt/V* for this patient would be 1.3.

$Kt/V = 54/42 = 1.3$

NOTE: A patient's average URR should exceed 65 percent. A patient's average *Kt/V* should be at least 1.2.

3.2.3 Drawbacks

The drawback concerning this procedure is that it requires blood samplings, and urea concentration measurements. The results are not immediately available because the samples must be sent for laboratory analysis, which means additional treatment costs. The accuracy of the results also depends on precise sampling timing, thus, the blood based urea Kt/V is not a very practical quality control tool for each dialysis treatment [7].

3.3 Urea monitor by Using Enzymatic sensors

These technique used by Urea Monitor 1000, from Baxter Healthcare Corporation .The technique is designed to measure urea concentration on-line in the effluent dialysate stream. The (UM) utilizes an ammonium ion sensor that measures the amount of ammonium ion (NH_4^+) determined directly by an ion-specific electrode [8].

$$CO[NH_2]_2 + H2O \xrightarrow{\text{Urease}} 2NH_3 + CO_2$$

$$NH_3 + H^+ \longrightarrow NH_4$$

In Equations above, Hydrolysis of urea, $CO[NH_2]_2$, produces NH_4^+, thus creating an electrical potential difference between two electrodes that is then amplified and recorded.

A membrane with the enzyme urease is the catalyst to the chemical reaction when it comes in contact with urea in the spent dialysate. The concentration of urea in mmol/L is measured every 5 minutes and the exponential decay is demonstrated [8].

3.3.1 Drawbacks

These systems for adequacy-monitoring have not found a wide utilization as clinical work for the staff.

3.4 Using Conductivity sensor (Ionic Dialysance)

In previous chapter explained the conductivity cell in general. This section will explain how to measure conductivity, ID and dialysis adequacy by using conductivity sensor.

3.4.1 How to Measure Conductivity

Conductivity may be measured by applying an alternating electrical current (I) at an optimal frequency to two active electrodes immersed in a solution and measuring the resulting voltage (V). During this process, the cations migrate to the negative electrode, the anions to the positive electrode and the solution acts as an electrical conductor[9].

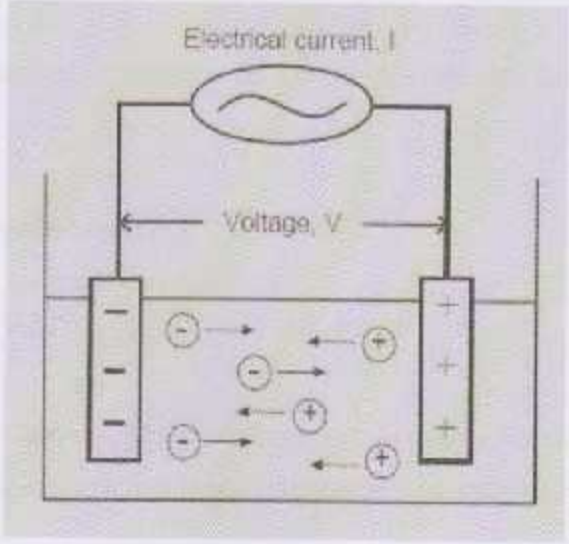


Figure 3.1: Migration of ions in solution

Resistance

The resistance of the solution (R) can be calculated using Ohm's law

$$V = R \times I \qquad (3.1)$$

$$R = V/I \qquad (3.2)$$

where:

V = voltage (volts)

I = current (amperes)

R = resistance of the solution (ohms)

Conductance

Conductance (G) is defined as the reciprocal of the electrical resistance (R) of a solution between two electrodes.

$$G = 1/R \ (S) \qquad (3.3)$$

The conductivity meter in fact measures the conductance, and displays the reading converted into conductivity.

Cell constant

This is the ratio of the distance (d) between the electrodes to the area (a) of the electrodes.

$K = d/a$ (3.4)

K = cell constant (cm^{-1})

a = effective area of the electrodes (cm^2)

d = distance between the electrodes (cm)

Conductivity

Electricity is the flow of electrons. This indicates that ions in solution will conduct electricity. Conductivity is the ability of a solution to pass current.The conductivity reading of a sample will change with temperature.

$C = G \cdot K$ (3.5)

C = conductivity (S/cm)

G = conductance (S), where G = 1/R

K = cell constant (cm^{-1})

3.4.2 How to Measure ID (Diascan)

The basic principle of the Diascan is the continuous measurement of the hemodialyzer outlet conductivity, when the inlet conductivity is changed for about 0.6mS/cm during 4 minutes.

The mathematical modeling of the outlet conductivity allows the calculation of two relevant parameters of the dialysis process : the Plasma conductivity and the Dialysance of ionised substances.

The DIASCAN system is based on the assumption that, the electrical conductivity of a dialysis fluid is linearly related to its ionic content, and mainly to its NaCl concentration.

Applying this concept, to the inlet dialysate conductivity C_{din} (as for all dialysis machines for the control of the dialysis fluid composition), and to the outlet dialysate conductivity C_{dout}, the continuous measure of C_{dout} for different values of C_{din} gives information linked to the ionic (and mainly NaCl) transfers through the membrane.

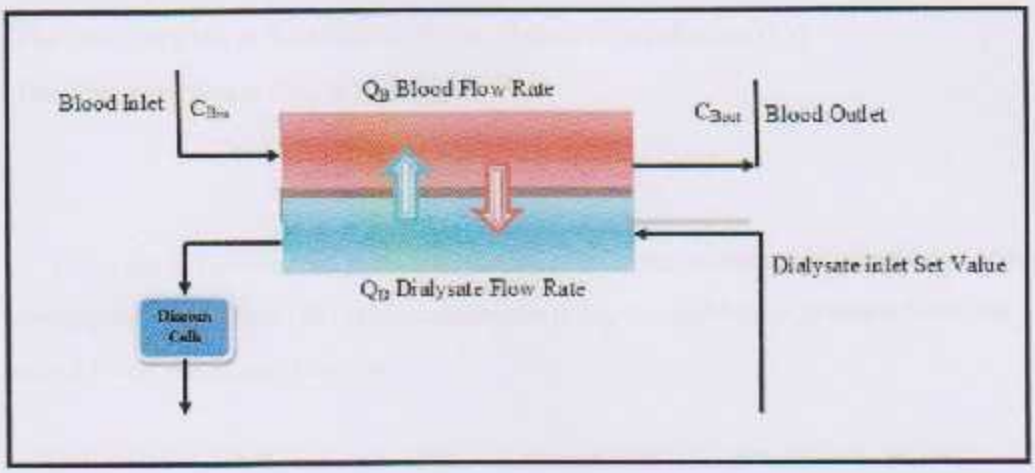


Figure 3.2: Step change in dialysate conductivity.

Figure 3.2 shows the principle is based on measurements of dialyzer inflow and outflow conductivities before and after a "step-change" in dialysate conductivity; Left: Schematics of a dialyzer with blood flow (black) and dialysate flow (grey). Right: Conductivity signals of dialysate inflow and outflow[8].

Transfers through the membrane are linked to :

- geometry of the dialyzer
- solute considered
- membrane permeability to the solute, dependent on the molecular weight of the solute.
- hydraulic status : Q_d, Q_b, Q_{UF} (Dialysate, blood and UF flow rates).

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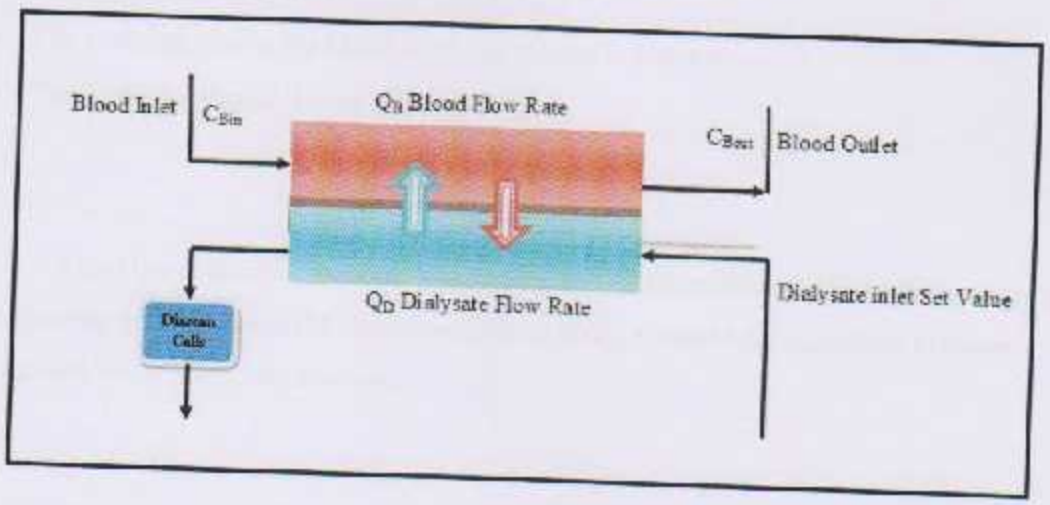

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Transfers through the membrane are linked to :

- geometry of the dialyzer
- solute considered
- membrane permeability to the solute, dependent on the molecular weight of the solute.
- hydraulic status : Q_d, Q_b, Q_{UF} (Dialysate, blood and UF flow rates).

For a given dialyzer in real treatment situation and fixed hydraulic status, transfers of urea and NaCl are equivalent because the molecular weight is 60 Dalton for urea and 58.5 for NaCl ; so urea transfer can be derived from the measure of NaCl transfer.

For a given solute (i.e. NaCl), the concentration at the dialyzer outlet is dependent on :

- The concentration at the dialyzer inlet (C_{din})
- The concentration at the blood inlet, the plasma concentration (C_b)
- The Transmembrane flux or Dialysance [19].

From the definition, the Ionic Dialysance (ID) is the relation between the quantity of solute crossing the membrane (M : trans-membrane flux), divided by the gradient between dialysate and blood inlet concentration.

$$M = (Q_d - Q_f) * (C_{dout2} - C_{dout1}) \qquad (3.6)$$

$$ID = M / (C_{din2} - C_{din1}) = (Q_d + Q_f)(C_{dout2} - C_{dout1}) / (C_{din2} - C_{din1}) \qquad (3.7)$$

Assuming that ID is equivalent to the urea clearance K, the parameter Kt/V can be assessed. The use of anthropometrical calculations often results in an overestimated V, which gives an underestimated Kt/V. Studies have focused on determining an accurate V either assessed by conductivity monitoring and it has also been suggested that the product of Kt, in mL/min is a better expression of dialysis clearance, due to V not being involved.

Chapter Four

Hardware System Design

4.1 Introduction

4.2 HD Flow Diagram

4.1.1 Blood Circuit

4.1.2 Dialysate Circuit

4.3 Project Diagram & Circuit

4.3.1 Wien Bridge Oscillator

4.3.2 Constant Current Source

4.3.3 Data Acquisition System (DAQ or DAS)

4.4 Circuit Calculation

4.1 Introduction

This chapter discussed and explains a hardware design of the project, its circuits, and calculation.

4.2 Hemodialysis (HD) Flow Diagram

Figure 4.1 shows Hemodialysis (HD) flow diagram and the position of the inlet Conductivity Cell and outlet conductivity cell (Diascan Cell), the block consists two parts: blood circuit and dialysate circuit.

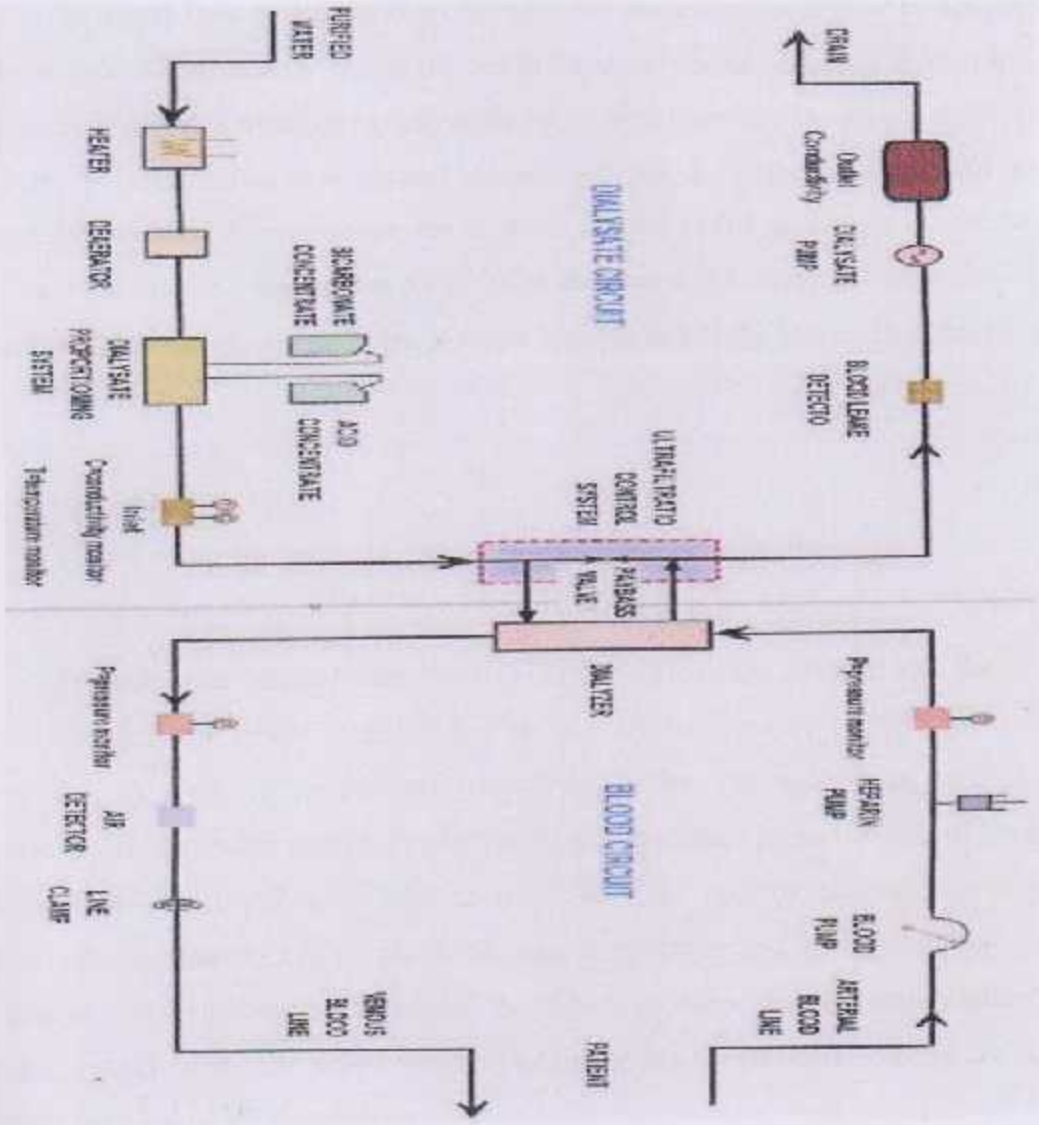


Figure 4.1: HD Flow Diagram

4.2.1 Blood Circuit

The patient's blood is continuously pumped by peristaltic blood pump from an artery, a large vein, or a surgically modified vein to allow high blood flow rates. Its pressure is monitored both upstream and downstream by using pressure sensor. Before the blood enters the dialyzer, heparin is added to prevent clotting. A syringe pump is used to deliver the heparin at a precisely controlled rate.

The blood then enters the dialyzer where it passes across a fiber in dialyzer. These fibers are made from semi- permeable membrane but the dialysate solution enters around the fibers in dialyzer. A pressure gradient is maintained across the membrane to ensure the proper flow of compounds out of and into the blood. After cleaning and balancing within the dialysate, the blood is passed through an air trap that contains ultrasound sensor to detect if there is any air bubbles in return blood or not, so if it's found the machine activate an air bubbles alarm and the clamp closed before it is returned to the patient and stop the blood pump, but if no air bubbles detect the blood return to the vein of patient.

4.2.2 Dialysate Circuit

Treated water inflows from the RO (Reverse Osmosis) system into the dialysis machine and passes through the heater ,water is heated to body temperature (33°–39°C) ,and it temperature is monitored by a special temperature monitoring device. Air bubbles in purified water removed by deaeration (air degassing pump). Proportioning pump assures proper mixing of heated water with fresh dialysate acid and bicarbonate solution to produce the appropriate dialysate solution. Temperature sensor and **conductivity cell** monitors dialysate temperature and the conductivity respectively , if there are problem in temperature or conductivity or both of them the dialysate solution passes to drain by activate bypass valve .But when the dialysate temperature and conductivity are correct the dialysate solution passes through the dialyzer.

Conductivity is the amount of electrical current conducted through a dialysate and reflects electrolyte concentration , a constant current is applied across two electrodes 1 cm apart in the dialysate flow. After exchange process complete between blood and dialysate solution the spent dialysate passes through the blood leak detector that detect if there is blood leak in spent dialysate or not. The waste dialysis solution withdrawn to drain by the dialysate pump. But as we shown in the previous flow diagram there are other conductivity cell in the outlet dialysate bath before going to drain, the main objective of it measure the outlet conductivity solution after exchange process which can be used to calculate the dialysis adequacy.

4.3 Project Block Diagram & Circuit

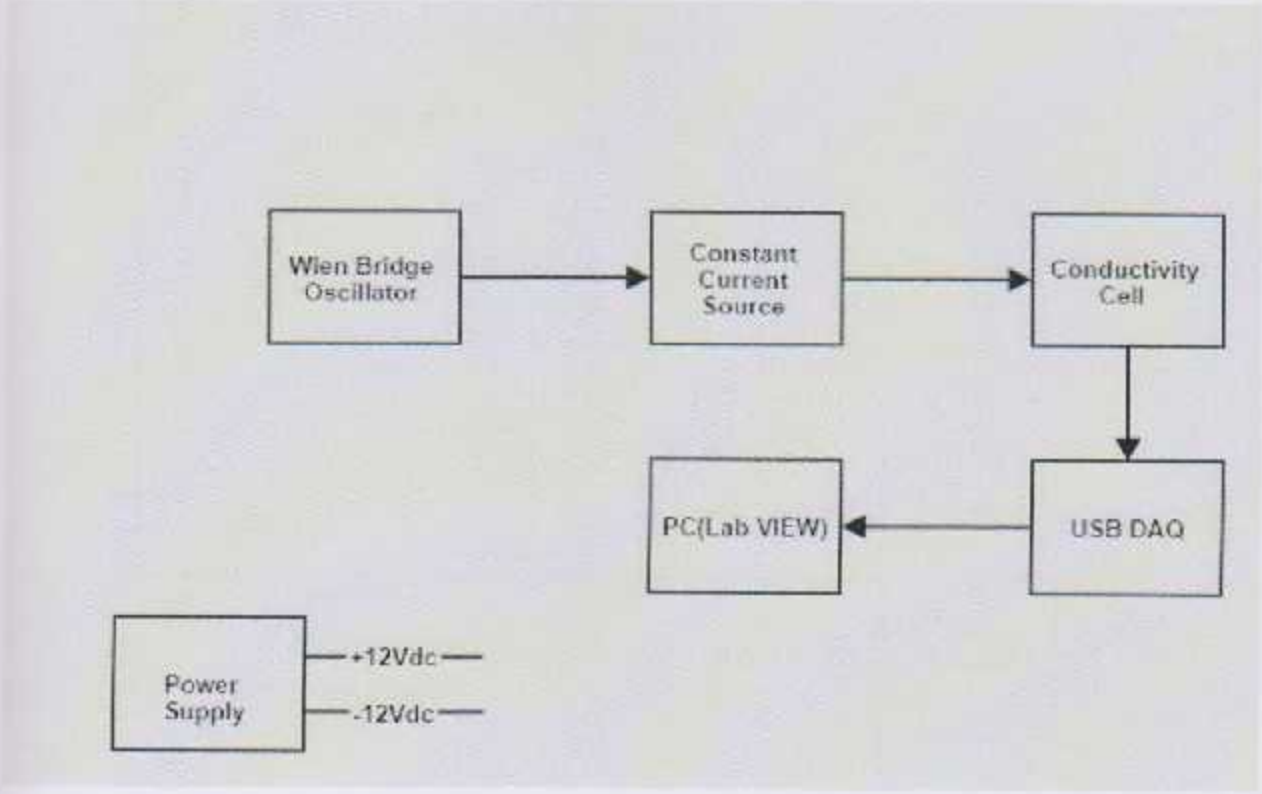
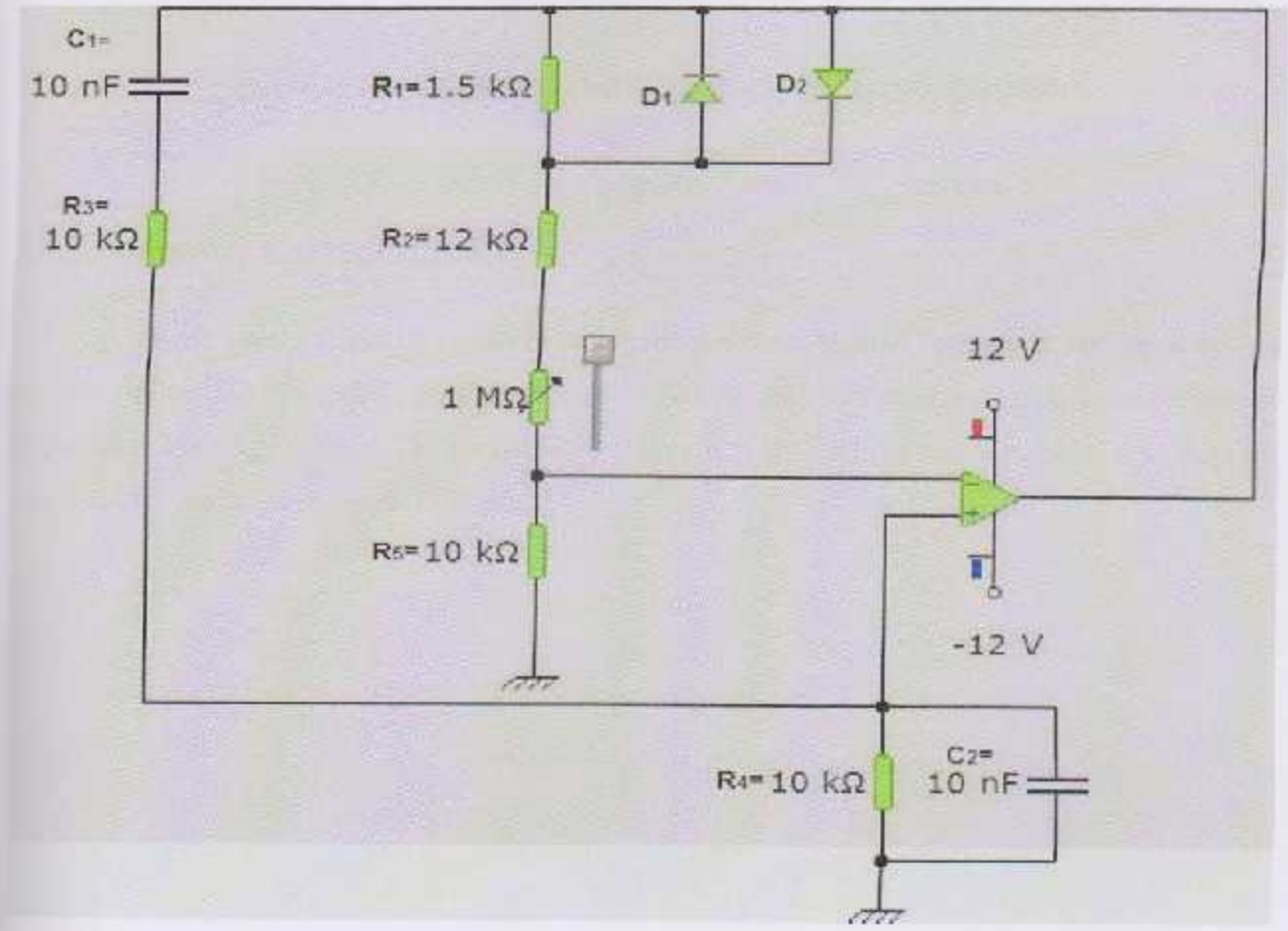


Figure 4.2 : Project Block Diagram

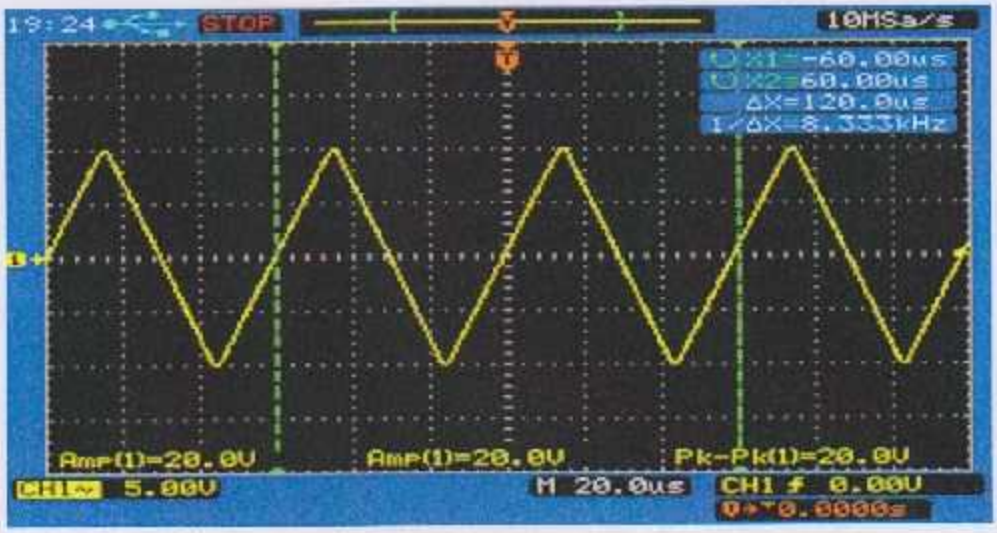
4.3.1 Wien Bridge Oscillator

A **Wien bridge oscillator** is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The oscillator is based on a bridge circuit originally developed by Max Wien in 1891. The bridge comprises four resistors and two capacitors. The oscillator can also be viewed as a positive gain amplifier combined with a band pass that provides positive feedback.

The circuit as shown in figure (4.3) was designed to create an electronic oscillator known as Wien Bridge Oscillator which can be used for the creation of specific frequency sine wave signals. The frequency of Wien bridge is 17 kHz and 20Vp-p.



(a)



(b)

Figure 4.3 : (a) Wien Bridge Oscillator circuit. (b) Output of the circuit.

4.3.2 Constant Current Circuit

A simple potential circuit is shown in Figure (4.4) in which an op–amp is combined with a conductivity cell. In this circuit, the existence of 10 KΩ resistor will produce 2 mA, since the output of the Wien bridge is 20Vp-p. The conductivity cell acts as variable resistance (according to solution conductivity) .So, voltage output produces.

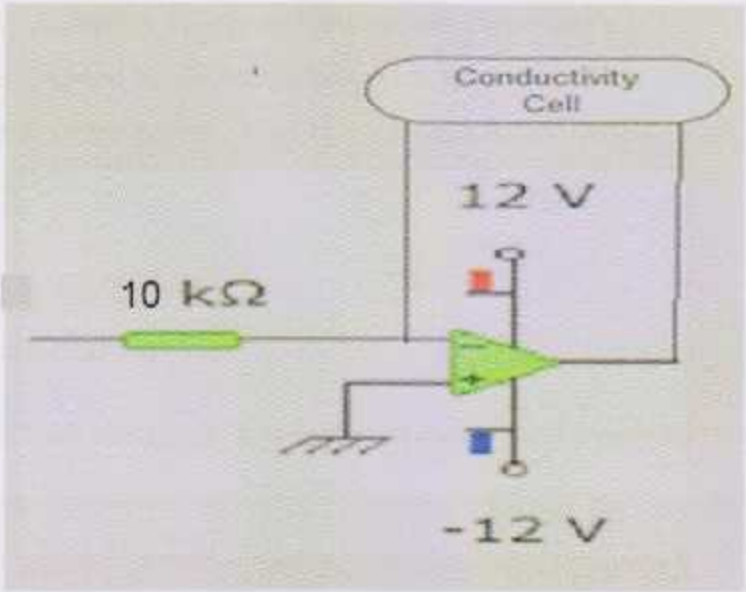


Figure 4.4 : Constant Current Source circuit.

The output voltage from the previous circuit transfer to the PC via USB DAS (Data Acquisition System). USB DAQ reads analog signal, whether the signal in +ve or/and -ve side. As a result, shift circuit irreplaceable.

4.3.3 Data acquisition system (DAS or DAQ)

DAQ is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems typically convert analog waveforms into digital values for processing. DAQ applications are controlled by software programs developed using various general purpose programming languages. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used. The signal may need to be filtered or amplified.

DAQ hardware is usually interfaces between the signal and a PC. It could be in the form of modules that can be connected to the computer's ports (parallel, series, USB) or cards connected to slots in the motherboard. In the project, USB DAQ is used .In PC we use LAB VIEW for estimating dialysis efficiency.

4.4 Circuit and calculation

Figure (4.5) shows the Wien bridge oscillator with constant current source and conductivity cell.

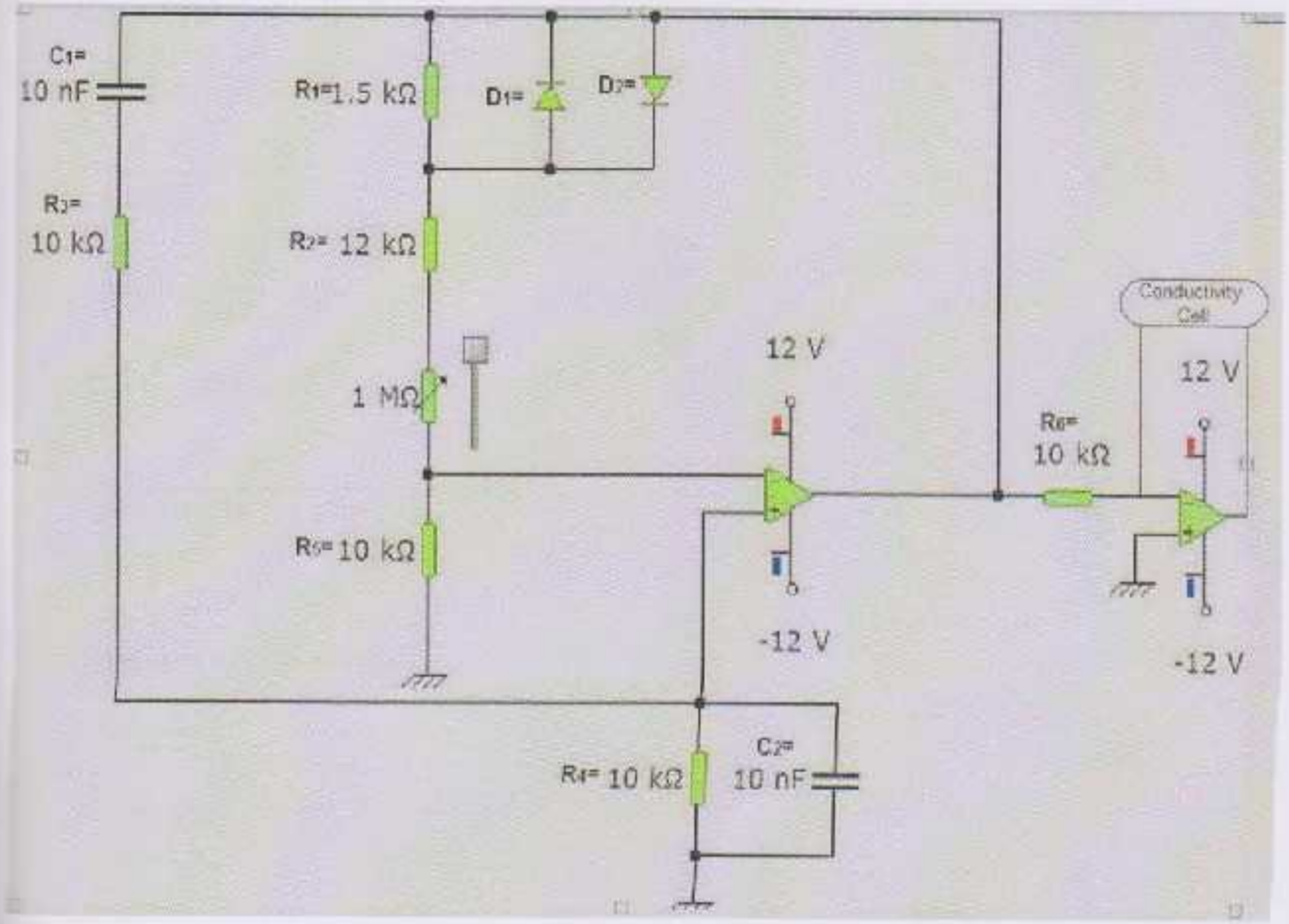


Figure 4.5 : Design Circuits

1) Practical Design Techniques

The design of Wien bridge oscillator circuit will perform according to the following design goals:

a. Frequency of oscillation 17kHz

b. Output voltage 20Vp-p

We will base our design on the accepted practice that $R_3 = R_4 = R_5 = R$ and $C_1 = C_2 = C$ .we will choose a value for C and compute the associated value for R. For our design, let us choose an initial capacitance value of 10nF. We can now compute the required value of R with equation 4.1 .

$$f = \frac{1}{2\pi RC} \qquad (4.1)$$

Or $R = \frac{1}{2\pi Cf}$

f=17 kHz , C= 10nF

$$R = \frac{1}{2\pi * 10 * 10^{-9} * 17 * 10^{3}} = 1\ \text{k}\Omega$$

2) Constant Current Source

R_6= 10 kΩ

V_o= 20 Vp-p

$$I_o = \frac{v_o}{R_6} \qquad (4.2)$$

$$= \frac{20v}{10\ \text{k}\Omega} = 2\ mA$$

Chapter Five

Software Design

5.1 Introduction

5.2 The Lab VIEW front panel

5.3 Watson formulas

5.4 Important Terminologies

5.5 Conductivity (C) and Ionic dialysis (ID) equation

5.6 Case Study

5.7 Project Flowchart

5.1 Introduction

Our project consists from two parts: Hardware part and software part. In software parts we are used the Lab View software program, and the following description equations used to programming it.

5.2 The Lab VIEW Front Panel

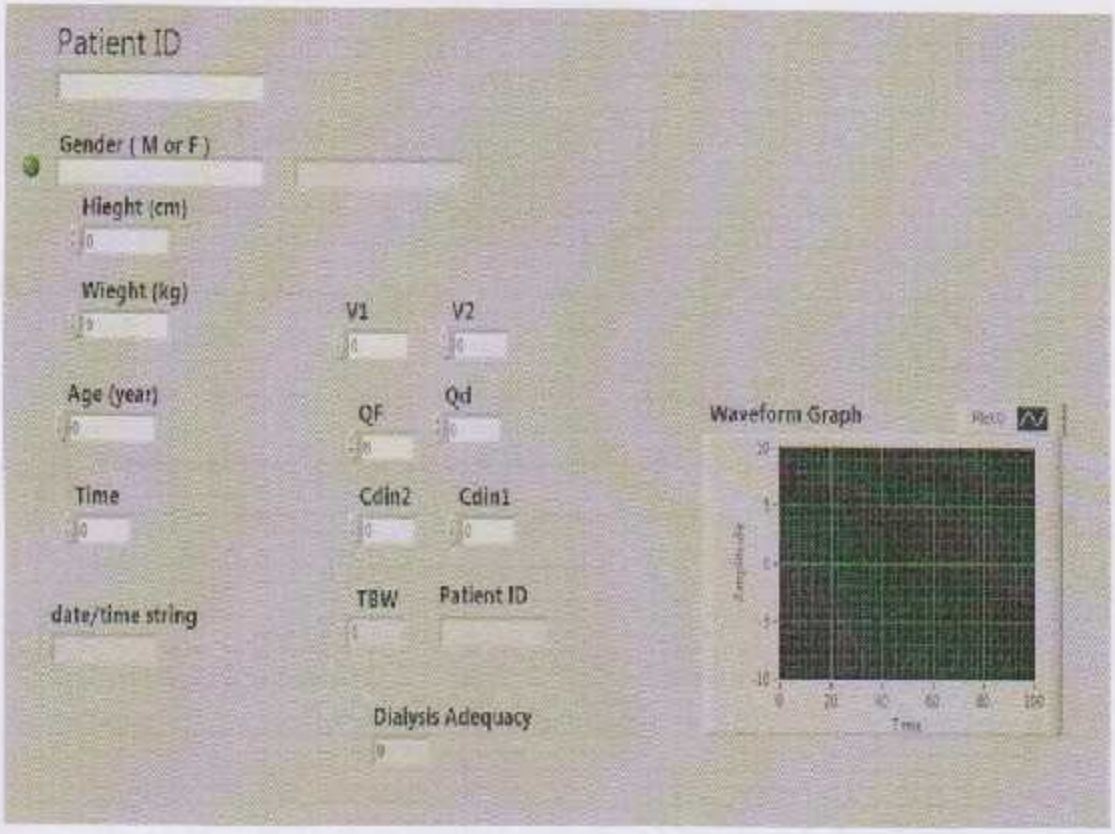


Figure 5.1: Lab VIEW front panel

LabVIEW(shortfor Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. We use the following equations to determine dialysis adequacy, seen in the following sections .

5.3 Watson Formulas

To determine the dialysis adequacy ($ID*t/TBW$), some information are needed. Patient gender (male or female), height in centimeter, weight in kilogram, and age in years. These four parameters used to compute total body water (measured in litter) via Watson formula [12].

$$Male\ TBW = 2.447 - (0.09156*age) + (0.1074*height) + (0.3362*weight) \quad (5.1)$$

$$Female\ TBW = -2.097 + (0.1069*height) + (0.2466*weight) \quad (5.2)$$

Dialysis Session Time: is the time required for complete session. Dialysis session time usually (180-240) minutes.

5.4 Important Terminology

- **Conductivity (C)**: a measure of the ability of a material to conduct an electric current or impulse. It is defined as the reciprocal of the resistivity of the material, and is expressed in Siemens m^{-1}.

- **Dialysis Flow Rate (Q_d)**: quantity of the solution mixture that is pulled to the filter every minute (300, 500, or 800 ml/min).

- **Blood Flow Rate (Q_b)**: quantity of the blood that is pulled to the filter every minute (usually from 180-400 ml/min).

- **Target Weight** : the weight that the patient loses it during HD session

- **Ultrafiltration Rate (Q_f)**: it's the quantity of water that moved from blood side to the dialysate side at every minute[9].

5.5 Conductivity (C) and Ionic dialysis (ID) equation

Conductivity (*C*) and ionic dialysis (*ID*) is determined by the following equations.

- **Conductivity** is determined by the by equation (5.3)

$$C = \frac{d}{a} * \frac{1}{R} = K * \frac{1}{R} \qquad (5.3)$$

Where

d: diameter of the conductivity cell tube.

a: area of the conductivity cell tube.

R: resistance.

- **Ionic dialysis** is determined by equation (5.4).

$$ID = (Q_d + Q_f)\left(\frac{C_{d\,out2} - C_{d\,out1}}{C_{d\,in2} - C_{d\,in1}}\right) \qquad (5.4)$$

Where :

C_{din1}: setting (inlet) dialysate conductivity which is considered in the dialysis session (usually equal 14mS/cm).

C_{din2}: rising (inlet) dialysate conductivity which is considered equal to 14.6mS/cm in the project.

C_{dout1}: outlet dialysate conductivity measured at C_{din1} in mS/cm unit.

C_{dout2}: outlet dialysate conductivity measured at C_{din2} in mS/cm unit.

- **Dialysis Adequacy:** This value is computed by dividing the product of time in summation of the IDs by the Volume Distribution, which is to be established by the clinician, according to the patient's dry weight and the ratio of the total Body Water to patient weight. This parameter allows the clinician to understand if the dialysis dose that has been achieved is adequate for the patient. It is a dimensionless variable measured using relative scale (varying from 0 to 2) [13].

  Dialysis adequacy is calculated by the equation (5.5) .

5.6 Case Study

In HD department at Hebron government hospital, patient has the following data:

Table 5.1: patient data

Patient ID	M.N
Height(cm)	165
Weight(kg)	80
Age(years)	52
Session time(hr)	3
Q_d(ml/min)	500
Q_b(ml/min)	284
Q_f(ml/min)	16.6
Target weight loss (kg)	3

During session, the following information obtained at different times.

Table 5.2: HD Session Data

Time	C_{dout1} At const. C_{din1}=14mS/cm	C_{dout2} At const. C_{din2}=14.6mS/cm
30	13.6	13.8
60	13.02	13.05
90	12.5	12.7
120	13.08	12.3
150	13.3	12.6

Data in table 5.2 taken by using **conductivity meter (model : YK-2005 CD)** that has *been used to measure conductivity values.*

Figure 5.2 : Conductivity Meter.

❖ ***Calculations***

By using (5.1) equation, since the gender is male :

$TBW = 2.447 - (0.09156 * 52) + (0.1074 * 165) + (0.3362 * 80)$

$= 42.306\ L = 42306\ mL$

Now , we calculate the Ionic Dialysance (ID) by using (5.4) equation.

$ID|_{30min} = (500 + 16.6) * abs[(13.8 - 13.6)/14.6 - 14] - 172 ml/min.$

So, the dialysis adequacy ($ID*T/V$) at that period is determined by (5.5) equation.

$$\textbf{\textit{Dialysis Adequacy}}\ (ID*T/V) = \frac{ID * time}{TBW} \qquad (5.5)$$

And since the procedure occurs every 34 minutes, time is constant and equal to 34.

$DA|_{30min} = (172 * 34)/42306 = 0.138.$

$ID|_{60min} = (500 + 16.6) * abs[(13.05 - 13.02)/0.6] = 258.3\ ml/min$

$DA|_{60min} = DA|_{30min} + (258.3 * 34)/42306$

$= 0.138 + 0.21$

$= 0.348$

$ID|_{90min} = (500 + 16.6) * abs[(12.7 - 12.5)/0.6] = 172.2\ ml/min$

$DA|_{90min} = DA|_{60min} + (172.2 * 34)/42306$

$= 0.158 + 0.138$

$= 0.296$

$$ID|_{120min} = (500+16.6)*abs[(13.3-13.08)/0.6] = 189.42\ ml/min$$

$$DA|_{120min} = DA|_{90min} + (189.42*34)/42306$$
$$= 0.296 + 0.152$$
$$= 0.448$$

$$ID|_{150} = (500+16.6)*abs[(13.6-13.3)/0.6] = 258.3\ ml/min$$

$$DA|_{150} = DA|_{120min} + (258.3*34)/42306$$
$$= 0.448 + 0.208$$
$$= 0.656.$$

The final value $0.656 < 1.2$, we conclude that the HD session is not good because the time is not sufficient .

5.7 Project Flowchart

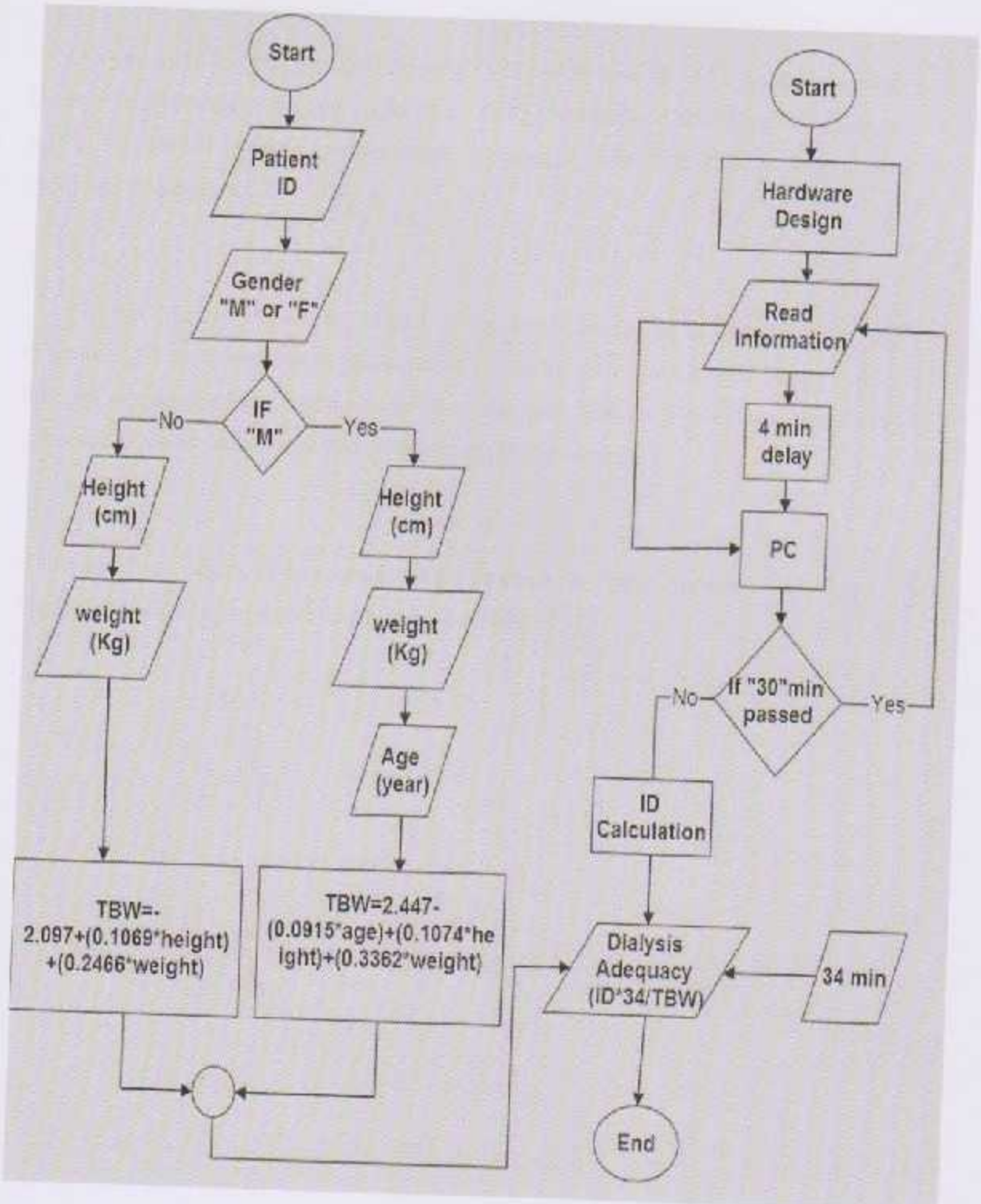


Figure 5.3 : Project flowchart

The flow chart consists of two parts. In the first one we ask operator to enter patient ID (letters, digits or both), and gender (M or F).

According to the gender, the following steps will follow. If ' M ', we ask operator to enter height, weight and age. After that, *TBW* is determined according to equation 5.1.If ' F ', we ask operator to enter height and weight. After that, *TBW* is determined according to equation 5.2.

In the other flowchart, the output of the hardware design is voltage. After 30 minutes, V_1 is measured and saved, conductivity at its normal value (14mS/cm). After that, we rise conductivity (up to 14.6mS/cm) manually and for 4 minutes. Then V_2 is measured. This process is repeated on the length of the session.

From previous values, and by using (3.1-3.8) equations, ionic dialysis is calculated. Finally, dialysis adequacy is calculated by equation (5.5).

Chapter Six

Results and Analysis

6.1 Introduction.

6.2 Study Design.

6.3 Conductivity Cell (3-Poles) using DC current On NaCl Solution.

6.4 Conductivity Cell (4-Poles) using AC current On NaCl solution.

6.5 Conductivity Cell (3-Poles) using DC current On HD Machine

6.6 Conductivity Cell (4-Poles) using AC current On HD Machine

6.7 Conclusion

6.8 Recommendation

6.1 Introduction

This chapter discussed and explains a results and analysis for the practical project.

6.2 Study Design

This study was designed to use Fresenius Hemodialysis machines (model 4008B). It was performed in Hebron at Hebron Government Hospital.

Hebron Government Hospital, Hemodialysis Unit, practical measurements were done during the period from April 20th ,2014 to May 21th , 2014 ; where (6) patients were selected, during (6) dialysis session. Only one type of dialyzer was used (low flux) as shown in Table (6.1). Bicarbonate dialysis powder was used. Dialysis treatment time was (180) minutes, and blood pump flow rate adjusted to be in range from (284-301) ml/min using one machine type .

Table-6.1: Materials and Adjusted Parameters

1-	**Hospital name and number of Patients**	
	Hebron Government Hospital	6
2-	**Age (years)**	
	Range	**26-64**
	Mean± standard deviation	**M (47.25 ± 14.728)** **F (58 ±8.485)**
3-	**Gender**	
	Male	**4 (66.67 %)**
	Female	**2 (33.33%)**

4-	**Height (cm)**	
	Range	**150-176**
	Mean± standard deviation	**M (169.25±4.7871)** **F (156.5±6.5)**
5-	**Type of dialysate**	
	Bicarbonate Powder	**6 (100 %)**
6-	**Dialyzer Type & Surface Area**	
	1.5 m^2 PS-1500L (Polysulphone)	**6 (100 %)**
7-	**Target weight loss (ml)**	
	Range	**500-4000**
	Mean± standard deviation	**M (2.5±1.29)** **F (1.75±0.357)**
8-	**Ultrafiltration rate (ml/min)**	
	Range	**8.33-25.1**
	Mean± standard deviation	**M (16.2±6.911)** **F (10.845±0.403)**
9-	**Dialysate flow rate (ml/min)**	
	Range	**500**
	Mean= standard deviation	**M (500±0.0)** **F (500±0.0)**
10-	**Dialysis treatment time (min)**	
	Range	**180**
	Mean± standard deviation	**M (180±0.0)** **F (180±0.0)**
11-	**Pump blood flow rate (ml/min)**	
	Range	**284-301**
	Mean± standard deviation	**M (294.7±7.544)** **F (294.75±12.02)**
12-	**Inlet dialysate conductivity (ms/cm)**	
	Range	**14-14.6**
	Mean= standard deviation	**14.1396 ± 0.01556**

13-	**Dialysate Temp (C)**	
	Range	37
	Mean± standard deviation	(37 ± 0.0)
14-	**Machine Type**	
	Fresenius 4008B	6 (100%)
15-	**Water Distribution Volume (litter)**	
	Range	26.76-52.573
	Mean± standard deviation	M (44.896±6.739) F (31.63±6.911)

6.3 Conductivity Cell (3-Poles) using DC current On NaCl Solution

Figure 6.1: shows the 3-poles conductivity cell.

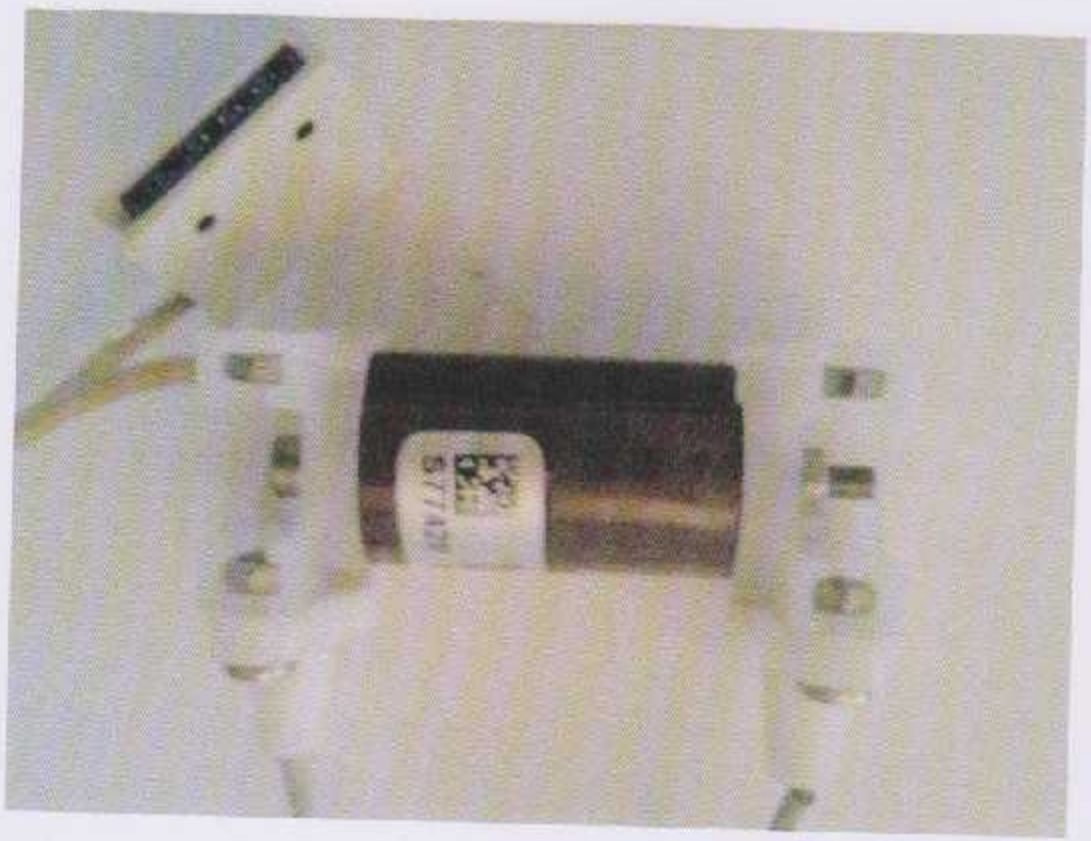


Figure 6.1: 3-poles conductivity cell.

- Results according to difference **NaCl** solution conductivity.

Table 6.2 shows the results of 3-poles conductivity cell by using DC current.

Table 6.2: results of 3-poles cell using DC current.

Solution	V_{out} (mV)	R* (ohm)	Temp. (C^0)	Conductivity (mS/cm)	Const.current (mA)
solution1	744	827	22	29	0.9
solution2	490	545	22	44	0.9
solution3	348.3	387	22	62	0.9

❖ **Analysis :**

By using different solutions with different conductivities, and measuring the output voltages. Then, at constant current (0.9mA), the resistance (R) is calculated by Ohms law . the conductivity is measured by conductivity meter.

6.4 Conductivity Cell (4-Poles) using AC current On NaCl solution

Figure 6.2: shows the 4-poles conductivity cell.

Figure 6.2: 4-poles conductivity cell

- Results according to difference **NaCl** solution conductivity.

Table 6.3: shows data of 4-poles conductivity cell. This data is used to compute cell constant (K).

Table 6.3: data of 4-pole cell

Solution	V_{out} (v)	Conductivity Measured(mS/cm)	Constant Current(mA)	R* (ohm)	K (cm^{-1})
Solution1	1.3	23.3	2.2	591	13.77
Solution2	1.26	111.7	2.2	572.7	13.34
Solution3	0.236	148.4	2.2	107.3	15.9
Solution4	0.2	155.4	2.2	91	14.14
Solution5	0.18	163.2	2.2	81.8	13.34

❖ **Analysis:**

Conductivity is measured by conductivity meter. And the impedence (R) is calculated by Ohms law ($R = V/I$).

To determine cell constant ($K = d/a$), according to the equation ($C = K/R$), and by using table 6.3 informations, K is calculated.

To determine a precision value of K, we compute the average.

$$K_{avg} = \frac{13.77+13.34+15.9+14.14+13.34}{5} = 14.098\ cm^{-1}$$

This value of K is used to calculate conductivity in table 6.4

Table 6.4: results of 4-poles cell using AC current.

ution	$V_{p\text{-}p\ out}$ (V)	Const. current (mA)	R* (ohm)	Temp. (C^0)	Conductivity* (mS/cm)	Figure#	Frequency (KHz)
lution	20	2	10000	22.9	0	6.3	17
r only	9	2	4500	22.9	3.13	6.4	17
tion1	2.22	2	1110	22.9	12.7	6.5	17
tion2	0.88	2	440	22.9	32	6.6	17
tion3	0.736	2	368	22.9	38.3	6.7	17
r only	11.2	2	5600	41.3	2.51	6.8	17
tion1	2.06	2	1030	41.3	13.68	6.9	17
tion2	0.912	2	456	41.3	31	6.10	17
tion3	0.72	2	360	41.3	39.16	6.11	17

❖ **Analysis:**

From the values of voltages and constant current, and by by using Ohms law ($R=V/I$), impedance (R) is calculated. And by using equation (3.5), C=K/R , conductivity (C) is computed .

❖ **Figures** related to table 6.4.

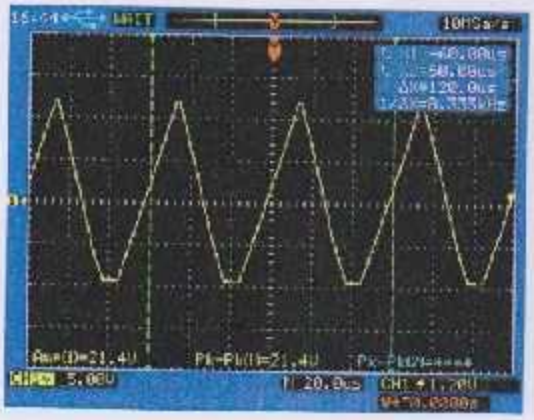


Figure 6.3: Out put signal with no solution

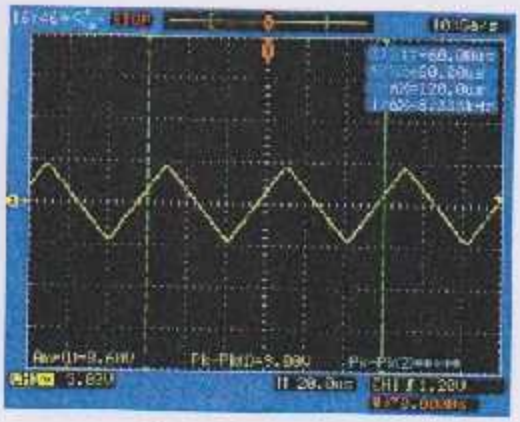


Figure 6.4: Water only

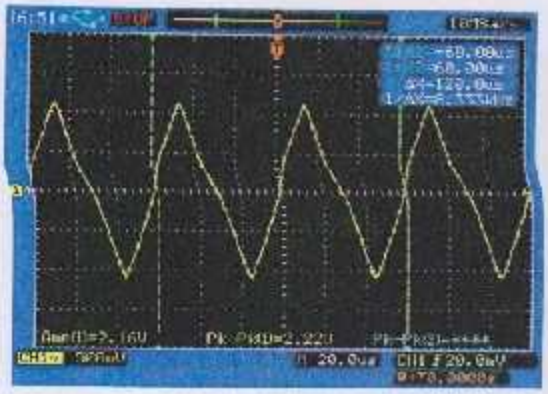


Figure 6.5:Output for solution1 in 22.9 C°

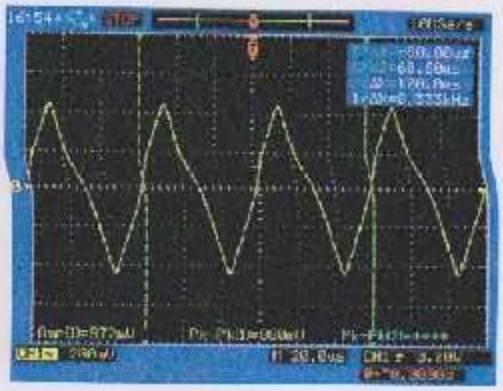


Figure 6.6:Output for solution 22.9 C°

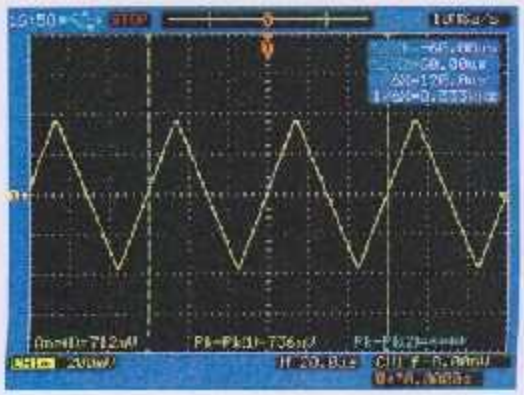


Figure 6.7: Output for solution 3 in 22.9C°

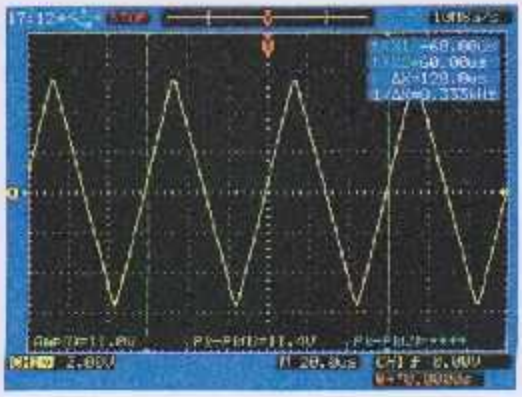


Figure 6.8: Output with water only

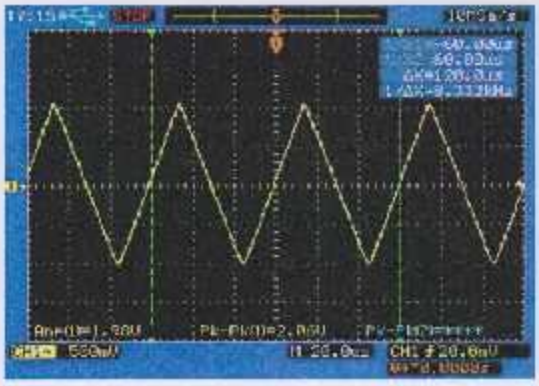


Figure 6.9:Output for solution 1 in 41.3C°

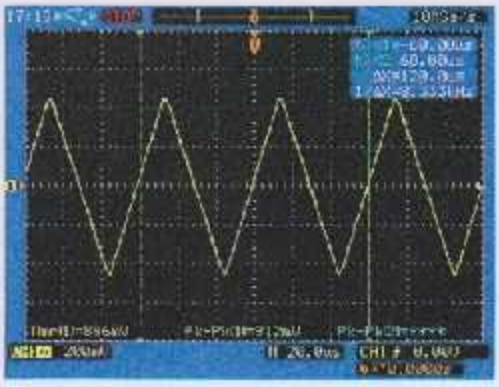


Figure 6.10: Out for solution 2 in 41.3C°

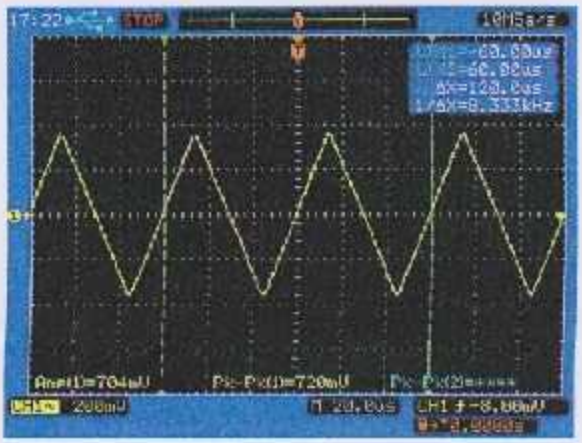


Figure 6.11: Output for solution 3 in 41.3C°

6.5 Conductivity Cell (3-Poles) using DC current On HD Machine

Table (6.5) shows the results of 3-poles conductivity cell by using DC current on patient ('A') HD session.

Table 6.5: the results of 3-poles conductivity cell by using DC current.

Time (min)	R_1 (kΩ)	R_2 (kΩ)	C_{din1} (mS/cm)	C_{din2} (mS/cm)	C_{dout1} (mS/cm)	C_{dout2} (mS/cm)	K_1 (cm^{-1})	K_2 (cm^{-1})
30	1.9	2.1	14	14.6	12.3	12.2	23.37	25.62
60	1.9	2.3	14	14.6	12.2	12.09	23.18	27.8
90	1.8	2	14	14.6	12.1	12.3	21.78	24.6
120	1.8	2.1	14	14.6	12	12.01	21.6	25.22
150	1.8	2.2	14	14.6	12.3	12.1	22.14	26.62

❖ Analysis :

In this session, the purpose is to determine the value of the cell constant (K) for 3-poles cell.

At constant current, and by measuring R_1 and R_2 at C_{din1} and C_{din2}, respectively. And by measuring the outlet conductivity (C_{dout1} & C_{dout2}) by conductivity meter, we can determine the value of cell constant(K).

By the equation (K=C*R), K_1 is calculated at difference values of R_1 & C_{dout1} along the HD session. Then the average of K_1 is calculated.

$$K_{1avg} = (23.37 + 23.18 + 21.78 + 21.6 + 22.14) / 5 = 22.414\ cm^{-1}.$$

And by using difference values of R_2 & C_{dout2} along the session , K_2 is calculated. Then the average of K_2 is calculated.

$$K_{2avg} = (25.62 + 27.8 + 24.6 + 25.22 + 26.62) / 5 = 26\ cm^{-1}.$$

To determine more accurate value of K, we take the average of K_1 and K_2.

$$K = \frac{K_1 + K_2}{2} = \frac{22.414 + 26}{2} = 24\ cm^{-1}$$

Table (6.6) shows the results of 3-poles conductivity cell by using DC current on patient ('B') HD session.

Table 6.6 : the results of 3-poles conductivity cell by using DC current

Time (min)	R_1 (kΩ)	R_2 (kΩ)	I (mA)	C_{din1} (mS/cm)	C_{din2} (mS/cm)	C_{dout1} (mS/cm)	C_{dout2} (mS/cm)
30	2.8	1.8	0.9	14	14.6	8.57	13.3
60	2.4	2.2	0.9	141	14.6	10	11
90	1.7	2.2	0.9	14	14.6	14.11	11
120	1.8	2	0.9	14	14.6	13.33	12

❖ **Analysis:**

In this session, the target is to calculate outlet conductivity (C_{dout1} & C_{dout2}).

R_1 is measured in kilo-ohm every 30 minutes, at C_{din1}.

R_2 is measured in kilo-ohm after 4 minutes of measuring R_1, at C_{din2}.

Then, we calculate outlet conductivity by (C = K/R) equation.

C_{dout1} is calculated at R_1 & at constant K=24 cm^{-1}.

C_{dout2} is calculated at R_2 & at constant K=24 cm^{-1}.

Table (6.7) shows the results of 3-poles conductivity cell by using DC current on patient ('C') HD session.

Table 6.7 : the results of 3-poles conductivity cell by using DC current

Time (min)	R_1 (kΩ)	R_2 (kΩ)	I (mA)	C_{din1} (mS/cm)	C_{din2} (mS/cm)	C_{dout1} (mS/cm)	C_{dout2} (mS/cm)
30	2.4	1.7	0.9	14	14.6	10	14.11
60	2.3	1.9	0.9	14	14.6	10.43	12.6
90	2.1	2.4	0.9	14	14.6	11.4	10
120	2.2	2.1	0.9	14	14.6	11	11.4
150	2.3	2	0.9	14	14.6	10.43	12

❖ **Analysis:**

In this session, the target is to calculate outlet conductivity (C_{dout1} & C_{dout2}).

_ R_1 is measured in kilo-ohm every 30 minutes, at C_{din1}.

_ R_2 is measured in kilo-ohm after 4 minutes of measuring R_1, at C_{din2}.

Then, we calculate outlet conductivity by (C = K/R) equation.

C_{dout1} is calculated at R_1 & at constant K=24 cm^{-1}.

C_{dout2} is calculated at R_2 & at constant K=24 cm^{-1}.

6.6 Conductivity Cell (4-Poles) using AC current On HD Machine

Table (6.8) shows the results of 4-poles conductivity cell by using AC current on patient ('D') HD session.

Table 6.8 : the results of 4-poles conductivity cell by using AC current

Time (min)	V_{1p-p} (V)	V_{2p-p} (V)	I (mA)	R_1 (kΩ)	R_2 (kΩ)	C_{dout1} (mS/cm)	C_{dout2} (mS/cm)
30	10.6	11	2	5.2	5.5	4.61	4.36
60	18.4	18.2	2	9.2	9.1	2.6	2.63
90	10.6	10.4	2	5.3	5.2	4.52	4.61
120	10.8	10.6	2	5.4	5.3	4.44	4.52
150	10.4	10.2	2	5.2	5.1	4.61	4.7

❖ **Analysis :**

In this session, the target is to calculate outlet conductivity (C_{dout1} & C_{dout2}) by measuring peak-to-peak voltage.

At constant current (2mA),V_{1p-p} is measured in volts every 30 minutes, at C_{dout1}. And V_{2p-p} is measured in volts after 4 minutes of measuring V_1, at C_{dout2}.

After that, by using ohms law, we calculate the impedancesR_1 & R_2 at V_{1p-p} & V_{2p-p} repectevely.

Then, we calculate outlet conductivity by (C = K/R) equation.

C_{dout1} is calculated at R_1 & at constant K=14 cm^{-1}.

C_{dout2} is calculated at R_2 & at constant K=14 cm^{-1}.

We want to determine the dialysis adequacy of the this session.

Table 6.9 : patient informations.

Patient ID	'D'
Gender	Male
Height (cm)	167
Weight (kg)	97
Age (year)	60
Q_d(ml/min)	500
Q_f(ml/min)	8.33
Q_b(ml/min)	295

❖ **Analysis:**

By using equation (5.1).

TBW = 2.447- (0.0915*60) + (0.1074*167) + (0.3362*97)

= 47.5 L

= 47500 ml

Table 6.10 : the results of dialysis adequacy of patient ('D') HD session.

Time	ID(ml/min)	DA
30	211.8	0.151
60	25	0.168
90	84.72	0.228
120	67.77	0.276
150	76.25	0.331

❖ **Analysis :**

Then, by using equations (5.4) and (5.5) .

$ID|_{30}$ = (500+8.33)*abs[(4.36-4.61)/0.6]
= 211.8 ml/min

$DA|_{30}$ = 34*211.8/47500
= 0.151

$ID|_{60}$ = 25 ml/min. so, $DA|_{60} = DA|_{30} + 0.017 = 0.168$.

$ID|_{90}$ = 84072 ml/min. so , $DA|_{90} = DA|_{60} + 0.06 = 0.228$.

$ID|_{120}$ = 67.77 ml/min. so, $DA|_{120} = DA|_{90} + 0.048 = 0.276$.

$ID|_{150}$ = 76.25 ml/min. so , $DA|_{150} = DA|_{120} + 0.055 = 0.331$

From the final result, $0.331 < 1.2$. we conclude the session is not good, because the session time is not sufficient.

6.7 Conclusion

From previous results, we conclude that:

1. Applying AC current is more accurate than DC current .

2. Using 4-poles conductivity cells is more accurate than using 3-poles conductivity cell.

3. Increase number of sessions leads to increase accuracy of results

6.8 Recommendation

1) Transfer data of HD machine by using wireless technique.

2) Make connection between software design and microcontroller of HD machine to take reading and rise the conductivity automatically.

3) For more accuracy, take reading for many HD session

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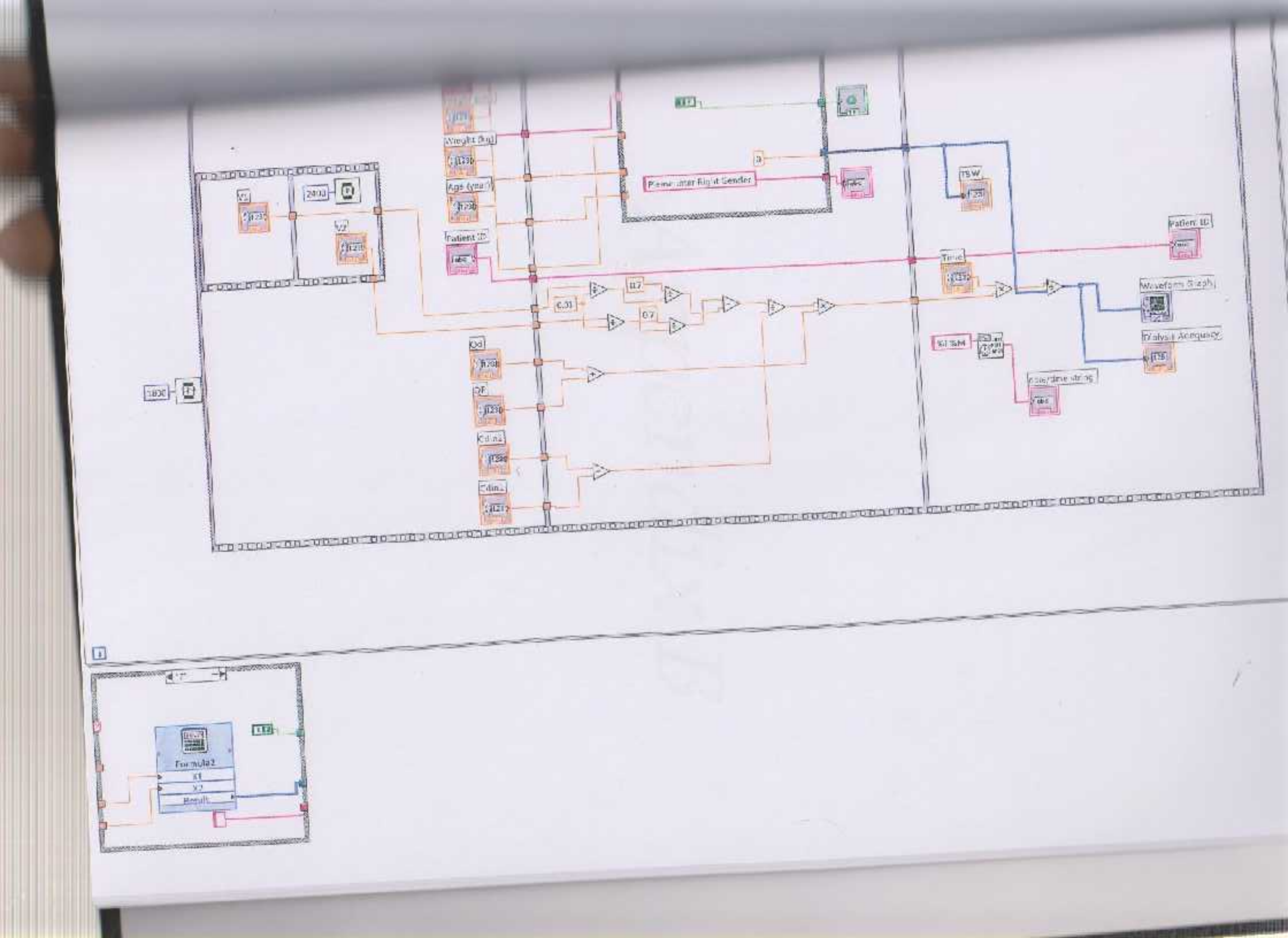

Weight (kg)
Age (year)
Patient ID
Parameter Right Gender
Time
Waveform Graph
Analysis Accuracy
Formula2
X1
Y2
Result

LM741 Operational Amplifier

Check for Samples: LM741

FEATURES

- Overload Protection on the Input and Output
- No Latch-Up When the Common Mode Range is Exceeded

DESCRIPTION

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Connection Diagrams

LM741H is available per JM38510/10101

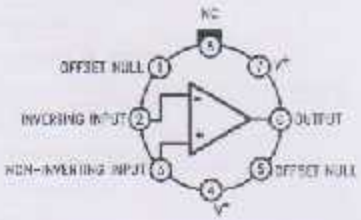


Figure 1. TO-99 Package
See Package Number LMC0008C

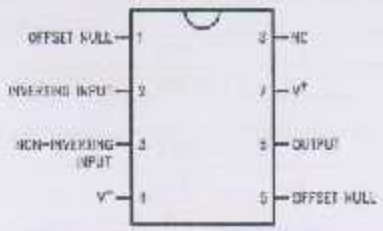


Figure 2. CDIP or PDIP Package
See Package Number NAB0008A, P0008E

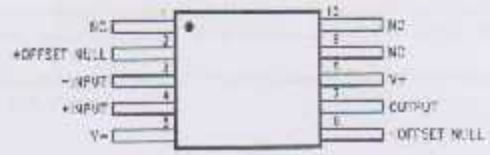


Figure 3. CLGA Package
See Package Number NAD0010A

Typical Application

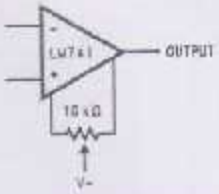


Figure 4. Offset Nulling Circuit

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings[1][2][3]

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation [4]	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage [5]	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
P0008E-Package (10 seconds)	260°C	260°C	260°C
NAB0008A- or LMC0008C-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C
ESD Tolerance [6]	400V	400V	400V

(1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
(2) For military specifications see RETS741X for LM741 and RETS741AX for LM741A.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(4) For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{JA} P_D)$.
(5) For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.
(6) Human body model, 1.5 kΩ in series with 100 pF.

Electrical Characteristics[1]

Parameter	Test Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	T_A = 25°C $R_S \le 10$ kΩ $R_S \le 50\Omega$		0.8	3.0		1.0	5.0		2.0	6.0	mV
	$T_{AMIN} \le T_A \le T_{AMAX}$ $R_S \le 50\Omega$ $R_S \le 10$ kΩ			4.0			6.0			7.5	mV
Average Input Offset Voltage Drift				15							µV/°C

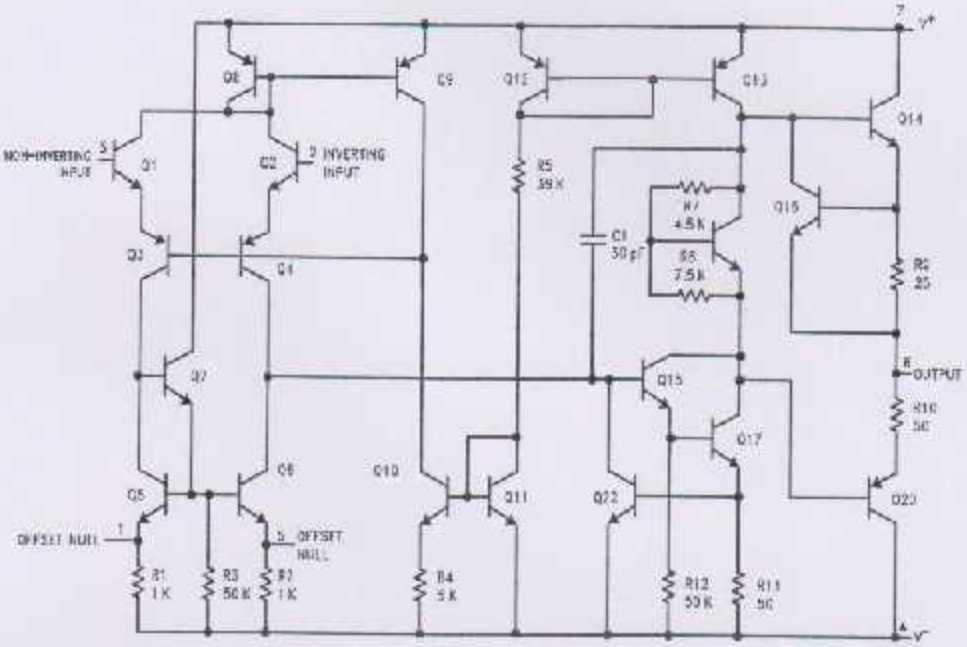
(1) Unless otherwise specified, these specifications apply for V_S = ±15V, −65°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

Electrical Characteristics[1] (continued)

Parameter	Test Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
LM741A	V_S = ±20V										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							
LM741	V_S = ±15V										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				

Thermal Resistance	CDIP (NAB0008A)	PDIP (P0008E)	TO-99 (LMC0008C)	SO-8 (M)
θ_{JA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{JC} (Junction to Case)	N/A	N/A	25°C/W	N/A

SCHEMATIC DIAGRAM



REVISION HISTORY

Changes from Revision B (March 2013) to Revision C	Page
• Changed layout of National Data Sheet to TI format	4