# A Systematic Review On High Flux And Medium Cut Off Membranes – Benchmarking Using Simulation Models

MANIPAL
ACADEMY of HIGHER EDUCATION
DUBAI CAMPUS
(Institution of Eminence Deemed to be University)

**Paper Presentation at**

## MRC-2023 Manipal Research Colloquium

## Abstract ID- MRCTS022

***Presenter: Ms. Ahana Fatima Alex***

Authors:

Ahana Fatima Alex
*Research Scholar*
*Department of Electrical and Electronics Engineering*
*Manipal Academy of Higher Education (MAHE)*
Dubai, UAE
Ahana.Fatima@dxb.manipal.edu

Dr. R Vinoth
*Department of Electronics and communication Engineering*
*Manipal Institute of Technology (MIT)*
*MAHE*
Manipal, India
vinoth.nair@manipal.edu

Dr. Ravishankar Dudhe
*Department of Electrical and Electronics Engineering*
*Manipal Academy of Higher Education (MAHE)*
Dubai, UAE
ravishankar.dudhe@manipaldubai.com

# Content

# Introduction

**"CLEANING THE BLOOD"**

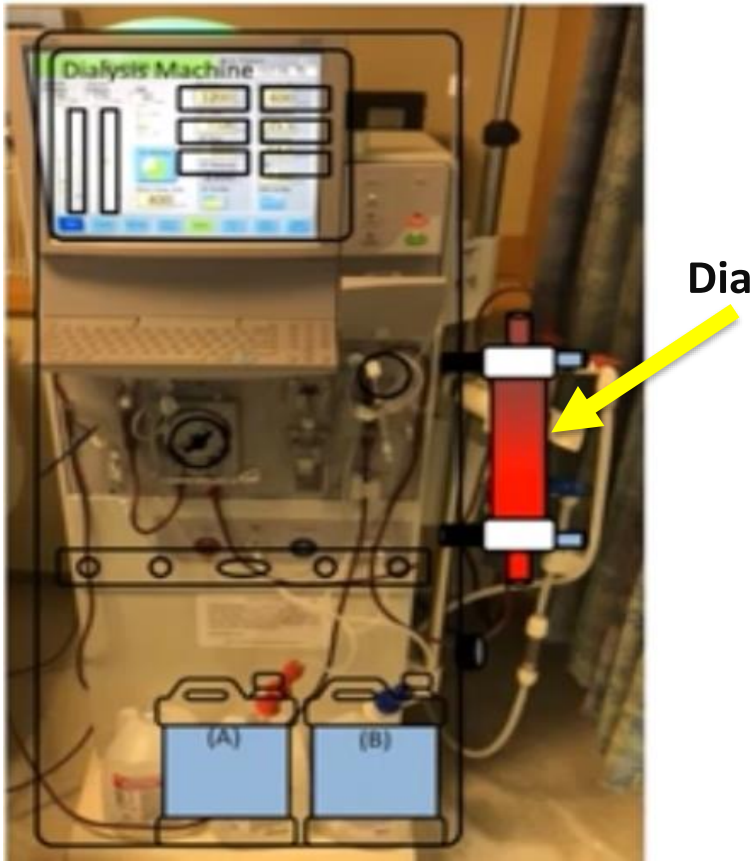
**MOST WIDELY FOLLOWED TREATMENT METHOD WORLDWIDE**

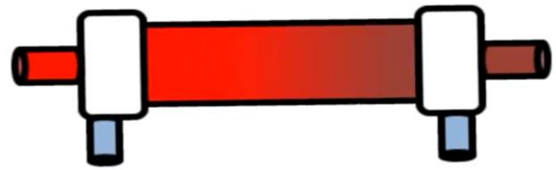
**BLOOD PURIFIED IN EXTRACORPOREAL FLUID CIRCUIT (OUTSIDE THE BODY)**

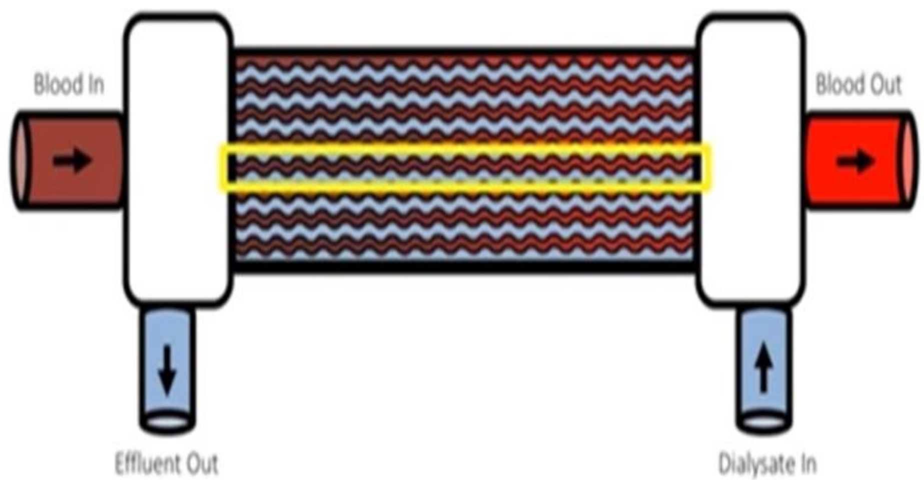
**EACH SESSION REMOVES 1-3 LITERS OF FLUID AND 50GMS OF UREMIC TOXINS.**

# Introduction







# Aim

MANIPAL
ACADEMY of HIGHER EDUCATION
DUBAI CAMPUS
(Deemed to be University under Section 3 of the UGC Act, 1956)
INSPIRED BY LIFE

Design – High performing membrane

- Eliminates maximum toxin
- Retain essential solutes

Major membranes by Fresenius and Baxter & Gambro

- Fx CorDiax 80
- Fx CorDiax 800
- RevaclearMax
- Optiflux F160NRe
- Optiflux F200NRe

*The literature supporting the study of these dialyzers are [2-15].*

*Literature [7, 11] - works by research and development team of Gambro, a unit of Baxter international inc. to improve the performance of hemodialyzer membranes and thereby optimize the dialyzer designs.*

- Model predicted - compared with the experimental results of literatures and data sheets for validation.

- Results of Revaclear and Optiflux validated with literatures whose study registered with ClinicalTrials.gov (identifier NCT00636077) [9-10].

# Literature Review

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS (Deemed to be University under Section 3 of the UGC Act, 1956)

| Sl no. | Authors/ Journal | Purpose Of Study | Key Findings |
|---|---|---|---|
| 1. | Donato D, Storr M, Krause B. "Design optimization of hollow fiber dialyzers to enhance internal filtration based on a mathematical model". Journal of Membrane Science. 2020 Mar 15; 598: 117690. | The study helped in modelling medium cut-off membranes focusing on the effect of internal filtration on clearance. The paper aimed at optimization | • Previously proposed model [9] was used to identify important factors that influences internal filtration (IF).<br>• **Maximal IF**<br>• Medium cut-off (MCO) membranes were used.<br>• Expanded dialysis<br>• Experimental data is used to validate the simulation results. |
| 2. | Islam, Md Shihamul. "Study of Dialyzer Membrane (polyflux 210h) and Effects of Different Parameters on Hemodialysis Performance." *PhD diss., University of Saskatchewan, 2013.* | The study too aimed at understanding the toxin clearance with respect to changes in different functional and geometric parameters. High flux membrane 210H was considered in this study. | The study supported in evaluating the toxin clearance for combinations of parametric changes. The paper was validated using experimental results and data sheets provided by manufacturers. |

# Literature Review

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS
(Deemed to be University under Section 3 of the UGC Act, 1956)

| Sl no. | Authors/ Journal | Purpose Of Study | Key Findings |
|---|---|---|---|
| 3 | Donato, D., Boschetti-de-Fierro, A., Zweigart, C., Kolb, M., Eloot, S., Storr, M., Segers, "Optimization of dialyzer design to maximize solute removal with a two-dimensional transport model". *Journal of Membrane Science*, *541*, 519-528, 2017. | Optimization of dialyzer design to maximize solute removal with a two-dimensional transport model. The study Claims that there is still room for optimal design. Various types of membranes were studied. COMSOL Multiphysics was used as the simulation tool and Two-Dimensional axisymmetric model was designed. | Therenova 400 MCO AA, FX CorDiax 80, FX CorDiax 800 and Revaclear Max were used for comparing and validating. Experimental data were also used for comparing results. The paper ensures sufficient solute removal, but losses weren't considered. |
| 4 | Bhimani JP, Ouseph R, Ward RA. "Effect of increasing dialysate flow rate on diffusive mass transfer of urea, phosphate and β2-microglobulin during clinical haemodialysis". Nephrology Dialysis Transplantation. 2010 Dec 1;25(12):3990-5. | The work aimed at understanding the performance of various toxins with respect to change in dialysate flow rate. The study mainly focused on membranes such as Revaclear Max and Optiflux | The work immensely helped in understanding the effect of different dialysate flow rate on toxin clearance. Clinical trials and in vivo experimentations were done in this study. The study was registered with clinicalTrials.gov (identifier: NCT00636077). |

# Methodology

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS (Deemed to be University under Section 3 of the UGC Act, 1956)

High performance membranes - Fx CorDiax 80, Fx CorDiax 800, Revaclear Max, Optiflux F160NRe and Optiflux F200NRe - modelled using finite element analysis software and their performances were studied.

[Models of Fx CorDiax 80 are elaborated in detail while only the results and comparison chart of other membrane models designed using the same methodology are depicted to showcase its uniqueness over other membranes.]

Uremic toxins of different molecular weight were made to pass through the membrane.

The blood flow rate $Q_b$ and dialysate flow rate $Q_d$ were varied from 200-800ml/min as per membrane type. The initial concentration of blood, $c_{in}$ was set at 1000 $mol/m^3$ for all cases and the final concentration $c_{out}$ was determined for each toxin molecule that passed through the membrane.

COMSOL Multiphysics 6.0 was the simulation tool used for all the designs. Transport of diluted species of chemical reaction module was the interface used and a stationary study was considered.

The numerical expression used to find K is as below.

$K = Q_b (c_{in} - c_{out}) / c_{in}$

# Methodology

MANIPAL ACADEMY of HIGHER EDUCATION
DUBAI CAMPUS
(Deemed to be University under Section 3 of the UGC Act, 1956)

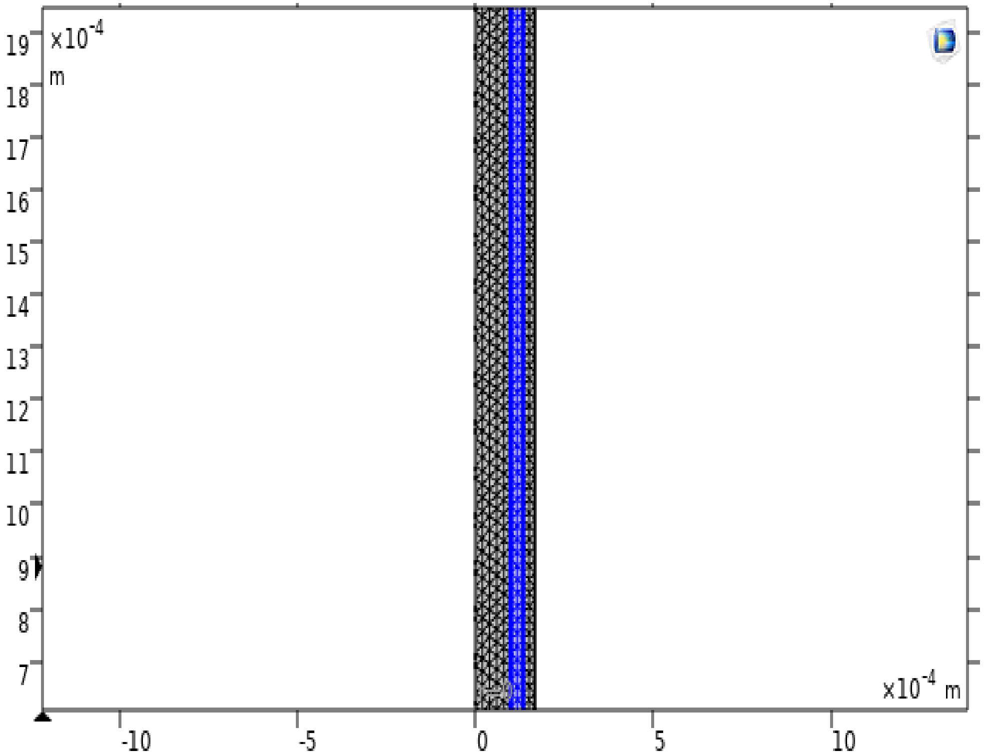
***Model 1 – Fx CorDiax 80***

LIST OF PARAMETERS USED FOR MODELING FX CORDIAX 80 [8]

| Parameter | Value |
|---|---|
| Inner radius of fiber | 0.175mm |
| Membrane thickness | 0.213mm |
| Width of dialysate channel | 0.245mm |
| Length of fiber | 270mm |
| Scale | 90 |
| Blood flow rate | 300ml/min |
| Dialysate flow rate | 500ml/min |
| Number of fibers | 12960 |
| Velocity of blood | (2*Q_b)/(3.1416*R1^2*n) |
| Velocity of dialysate | -((2*Q_d)/(3.1416*((0.75*R3^4)+(0.25*R2^4)-(R2^2*R3^2)-(R3^4*log(R3/R2)))*n)) |
| Inlet concentration, $c_{in}$ | 1000mol/$m^3$ |

# Results

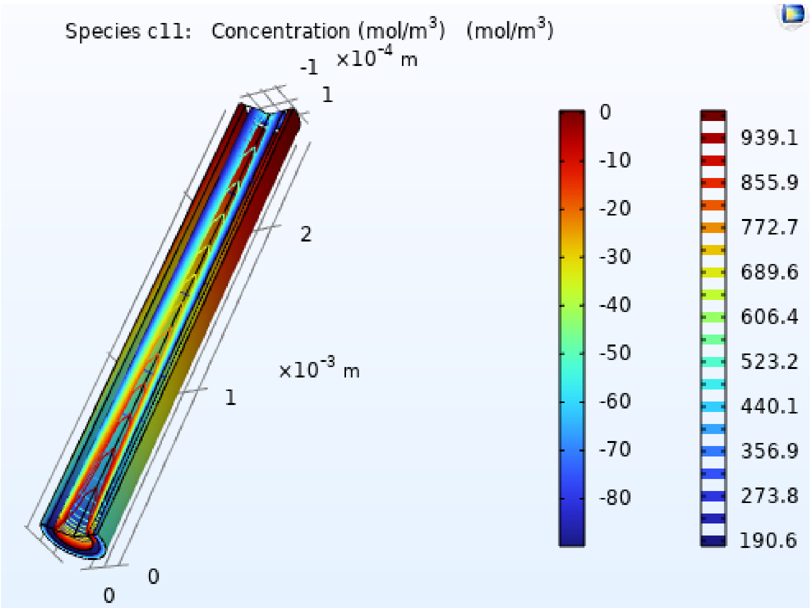
MANIPAL
ACADEMY of HIGHER EDUCATION
DUBAI CAMPUS
(Deemed to be University under Section 3 of the UGC Act, 1956)




Meshed geometry of Fx CorDiax 80

The toxins that were made to pass through the dialyzer membrane

- Urea
- Phosphate
- creatinine
- myoglobulin.




3-D view concentration and contour plot of Fx CorDiax 80

# Results

Manipal Academy of Higher Education, Dubai Campus
(Deemed to be University under Section 3 of the UGC Act, 1956)
Inspired by Life

***Model 2 – Fx CorDiax 800, Revaclear Max, Optiflux F160NRe and Optiflux F200NRe***

| Toxin | Qb | Qd | Cout | K , Simulation | K, Literature |
|---|---|---|---|---|---|
| Urea | 300 | 500 | 123.7 | 262.89 | 271 |
| Urea | 400 | 500 | 192.57 | 322.972 | 317 |
| Urea | 400 | 600 | 197.26 | 321.096 | 332 |
| Urea | 400 | 800 | 203.31 | 318.676 | 349 |
| Urea | 500 | 800 | 265.19 | 367.405 | 394 |
| Urea | 600 | 800 | 317.4 | 409.56 | 423 |
| Creatinine | 300 | 500 | 172.3 | 248.31 | 242 |
| Creatinine | 400 | 500 | 249.14 | 300.344 | 274 |
| Creatinine | 400 | 600 | 253.66 | 298.536 | 288 |
| Creatinine | 400 | 800 | 259.46 | 296.216 | 302 |
| Creatinine | 500 | 800 | 323.63 | 338.185 | 331 |
| Creatinine | 600 | 800 | 375.82 | 374.508 | 350 |
| Phosphate | 300 | 500 | 222.95 | 233.115 | 241 |
| Phosphate | 400 | 500 | 304 | 278.4 | 279 |
| Phosphate | 400 | 600 | 308.29 | 276.684 | 290 |
| Phosphate | 400 | 800 | 313.65 | 274.54 | 304 |
| Phosphate | 500 | 800 | 377.83 | 311.085 | 340 |
| Phosphate | 600 | 800 | 428.62 | 342.828 | 369 |

Clearance rate of toxins – Simulation Vs Literature, Optiflux F160NRe

Literature, Fx CorDiax 800

| Toxin | Qb | Qd |
|---|---|---|
| Urea | 400 | 50 |
| Phosphate | 400 | 50 |
| Creatinine | 400 | 50 |

- While in Optiflux F160N…
  flow rate was varied fron…

…elled and simulated.

….

…Simulation Vs. Literature,
…ar max

| …t | K, Simulation | K, Literature |
|---|---|---|
| .64.32 | 334.27 | 339 |
| 255.41 | 297.83 | 297 |
| .71.06 | 331.58 | 311 |
| .73.55 | 330.58 | 295 |
| 264.03 | 294.39 | 184 |
| 180.3 | 327.88 | 126 |

# Conclusion

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS (Deemed to be University under Section 3 of the UGC Act, 1956) INSPIRED BY LIFE

Fx CorDiax 80, Fx CorDiax 800, Revaclear Max, Optiflux F160NRe and Optiflux F200NR- designed and modelled to observe the clearance rate of various toxins at different velocities of blood and dialysate.

The outcome shows close approximation with the experimental data from literature and manufacturers data.

Membranes thus modelled- superior to the existing conventional high flux membranes and can be used for patient-specific treatment purposes as in use of MCO membranes in expanded hemodialysis.

The results also predict that Revaclear Max and Fx CorDiax series are of good performance and can be further studied for improvisation in the model to achieve optimization.

One step closer to optimization.

# Reference

MANIPAL ACADEMY of HIGHER EDUCATION DUBAI CAMPUS (Institution of Eminence Deemed to be University) INSPIRED BY LIFE


1. Diabetes.co.uk – the global diabetes community
2. Islam, Md Shihamul. "Study of Dialyzer Membrane (polyflux 210h) and Effects of Different Parameters on Hemodialysis Performance." *phd diss., University of Saskatchewan, 2013.*
3. Turgeon, Mary Louise. *Clinical hematology: theory and procedures*. Lippincott Williams & Wilkins, 2005.
4. Gambro Polyflux H Available at: https://renalcare.baxter.com (Accessed in August 2022).
5. Ouseph R, Hutchison CA, Ward RA. Differences in solute removal by two high-flux membranes of nominally similar synthetic polymers. Nephrology Dialysis Transplantation. 2008 May 1;23(5):1704-12.
6. Ward RA, Ouseph R. Modification of membrane characteristics allows a reduction in dialyzer membrane area without loss of performance. Inproceedings of the 40th American Society of Nephrology Congress 2007 Nov 3 (pp. 2-5).
7. Donato, D., Boschetti-de-Fierro, A., Zweigart, C., Kolb, M., Eloot, S., Storr, M., ... & Segers, P. (2017). Optimization of dialyzer design to maximize solute removal with a two-dimensional transport model. *Journal of Membrane Science*, *541*, 519-528.
8. Eloot S, d'asseler Y, De Bondt P, Verdonck P. Combining SPECT medical imaging and computational fluid dynamics for analyzing blood and dialysate flow in hemodialyzers. The International journal of artificial organs. 2005 Jul;28(7):739-49.
9. Kirsch AH, Lyko R, Nilsson LG, Beck W, Amdahl M, Lechner P, Schneider A, Wanner C, Rosenkranz AR, Krieter DH. Performance of hemodialysis with novel medium cut-off dialyzers. Nephrology Dialysis Transplantation. 2017 Jan 1;32(1):165-72.
10. Bhimani JP, Ouseph R, Ward RA. Effect of increasing dialysate flow rate on diffusive mass transfer of urea, phosphate and β2-microglobulin during clinical haemodialysis. Nephrology Dialysis Transplantation. 2010 Dec 1;25(12):3990-5.
11. Donato, D., Storr, M., & Krause, B. (2020). Design optimization of hollow fiber dialyzers to enhance internal filtration based on a mathematical model. *Journal of Membrane Science*, *598*, 117690.
12. Therenova 400 Data sheet Available at: https://renalcare.baxter.com (Accessed in August 2022).
13. Optiflux Dialyzers Available at: https://fmcna.com (Accessed in August 2022).
14. Revaclear Available at: https://www.baxter.com (Accessed in August 2022).
15. Fx cordiax Available at: http://www.bcrenal.ca (Accessed in August 2022).


Thankyou