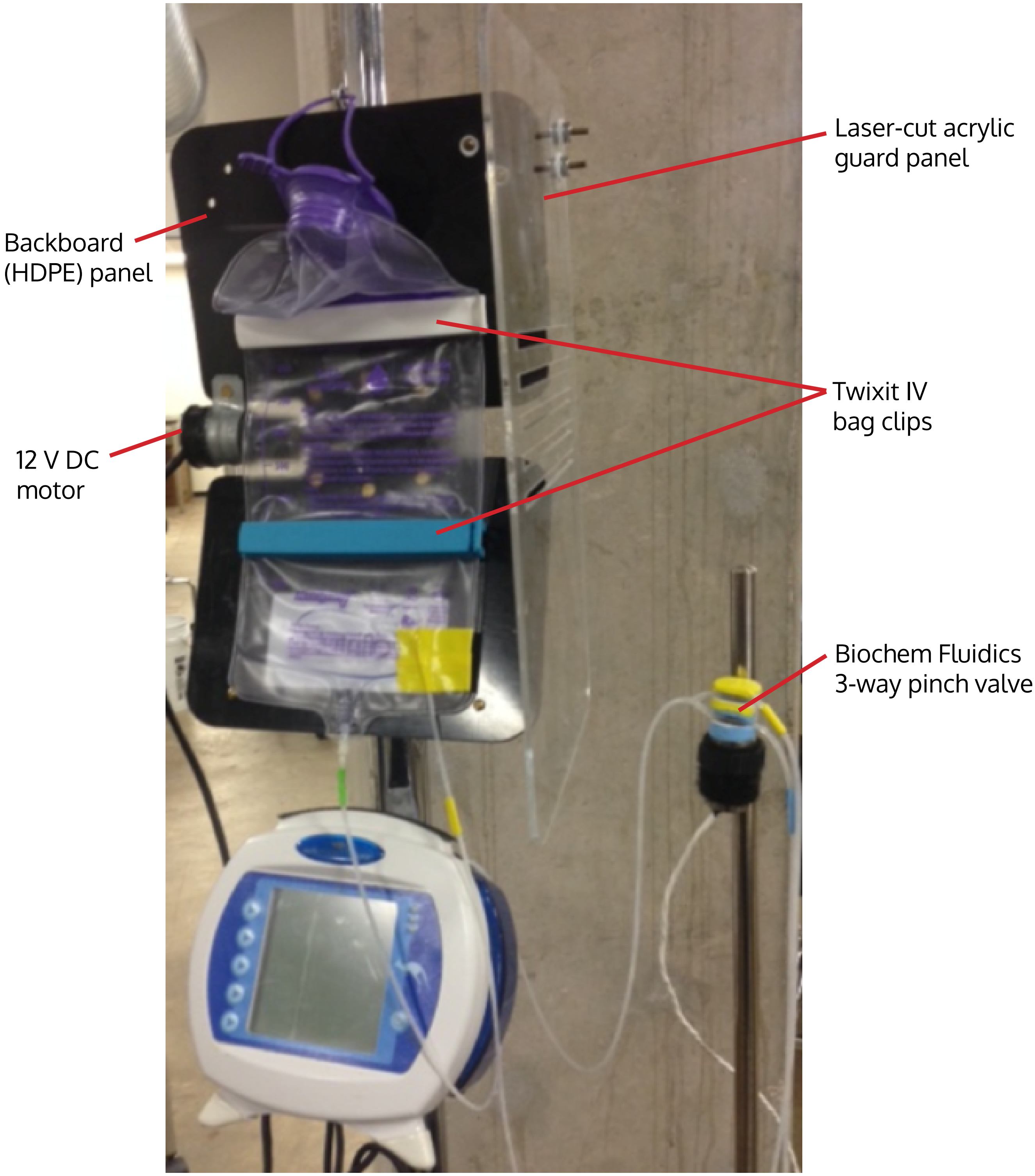
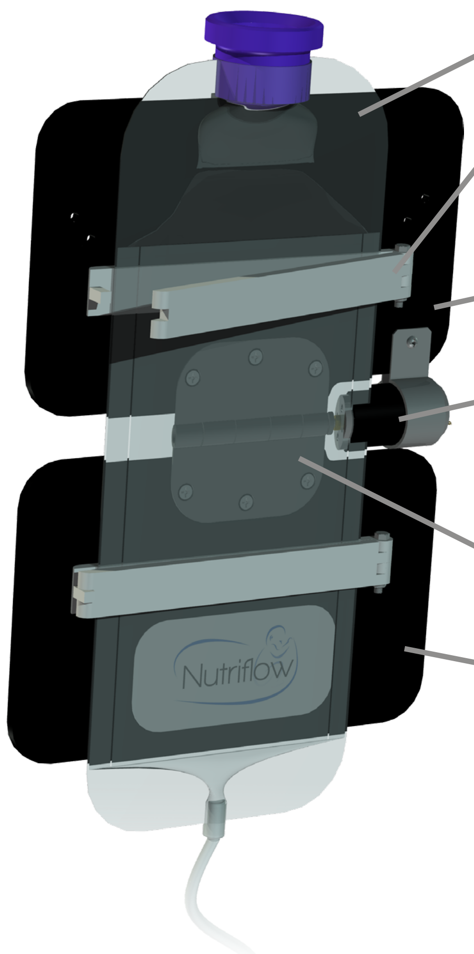
Labeled Nutriflow device without additional bypass pump attached



MILK BAG INVERTER CAD DRAWINGS

Existing enteral feeding systems lose **up to 50%** of milkfat and other fat-borne nutrients in breast milk over a 1-hour feed, with nearly **60% of this loss occuring in the bag alone**. Our inversion system reduces fat separation in milk by inverting the milk bag every 3 minutes over the feed. Preliminary results show that up to 90% of the milkfat may be retained in milk exiting the bag.



Kangaroo feed bag

Bag clips (Focus B) allow easy mounting of feed bag and restriction of surface area of milk exposure

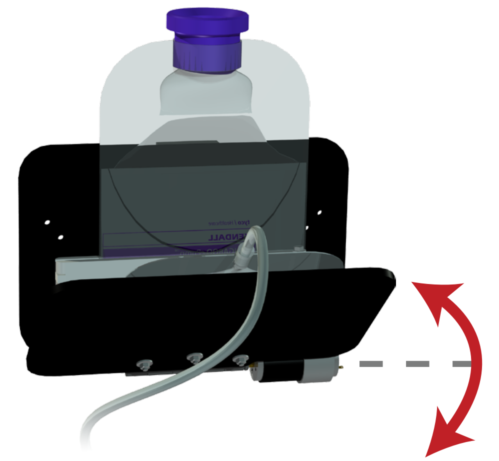
HDPE 1/8" **top backboard pane**

Programmed DC motor (Focus A) rotates milk volume in bag to inverted state once every 3 minutes

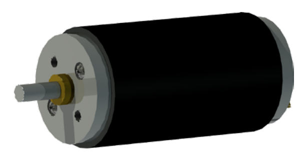
Everbilt™ 3 in. door hinge

HDPE **bottom pane**

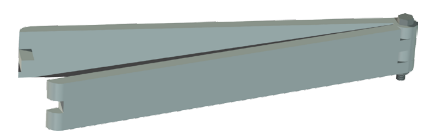
NON-INVERTED STATE



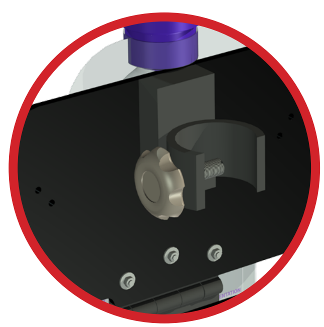
INVERTED STATE



A. 12V DC Motor



B. Bag Clip

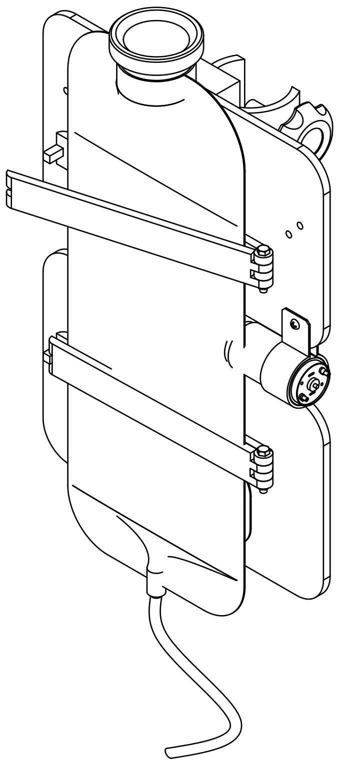


Easy mounting to IV poles

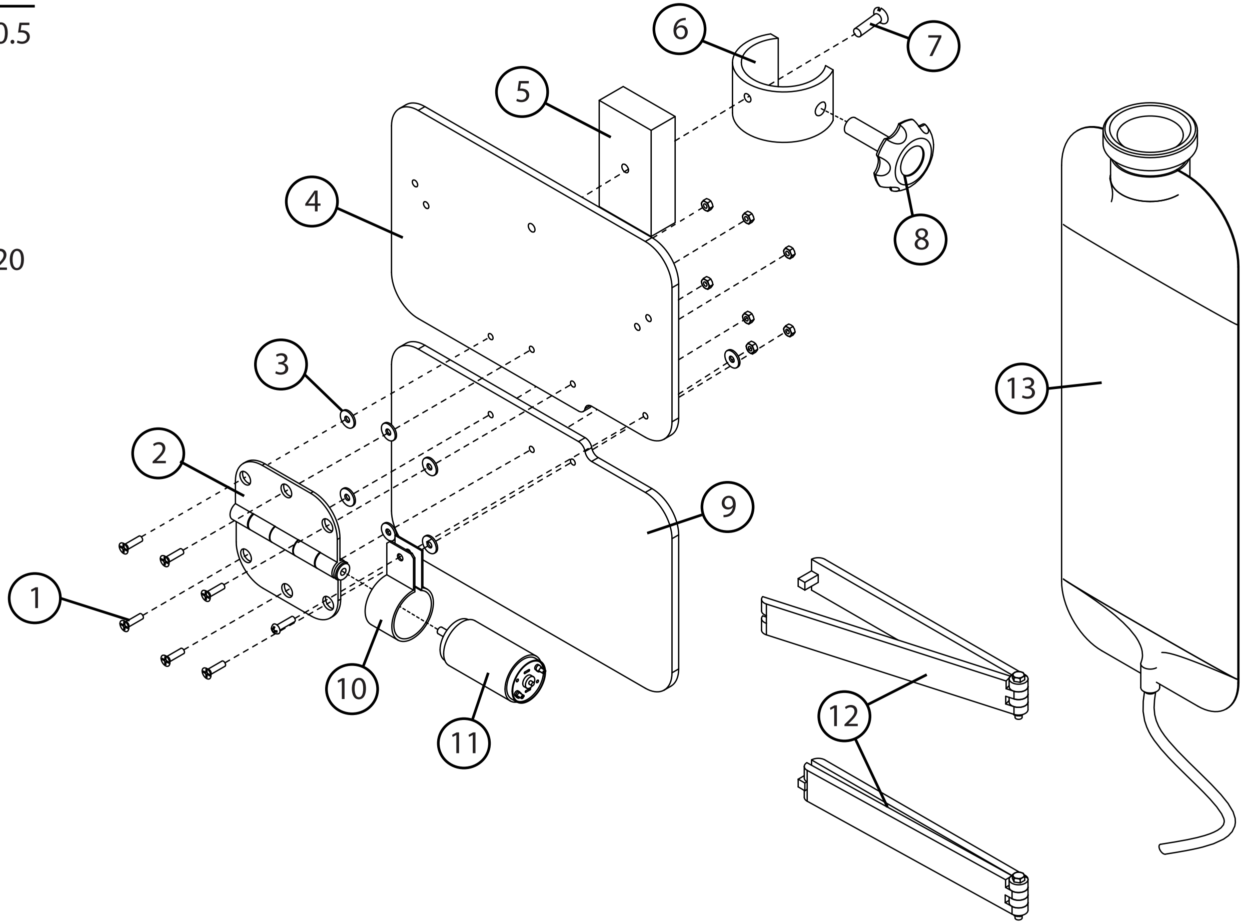
Screw knob mounted to back of top pane facilitates easy mounting and removal of device.

BILL OF MATERIALS

PART NO.	QTY.	DESCRIPTION
1	6	Screw: Countersunk - 0.125x0.5
2	1	Everbilt 3" Door Hinge
3	6	Washer: Plain - 0.125x0.04
4	1	Top Backboard Panel
5	1	1x2x4 in. oak block
6	1	Split 2" Diameter PVC
7	1	Screw: Countersunk - M5.0x20
8	1	Screw: Knob - M9.45x35.0
9	1	Bottom Backboard Panel
10	1	Bent 6" shelf bracket
11	1	DC 12 V 25 RPM Motor
12	2	Twixit 5" Bag Clips
13	1	Kangaroo Bag and Tubing



COMPLETED ASSEMBLY



EXPLODED VIEW

A4

ISO E

IronCAD
2D drawing
3D file available

Scale: 1:4 (mm)

General Tolerances acc to: ISO 2768-1 medium

File Name: MachineDrawingsNew.icd

Last saved: 5/3/2014 11:24 PM

Drawn by: NL

Checked by:

Approved by:

Created Date: 05/03/14

Team Nutriflow

Description

BAG INVERTER ASSY.

Sheet No: 1 (2)

Rev. 2

Doc. No: 2

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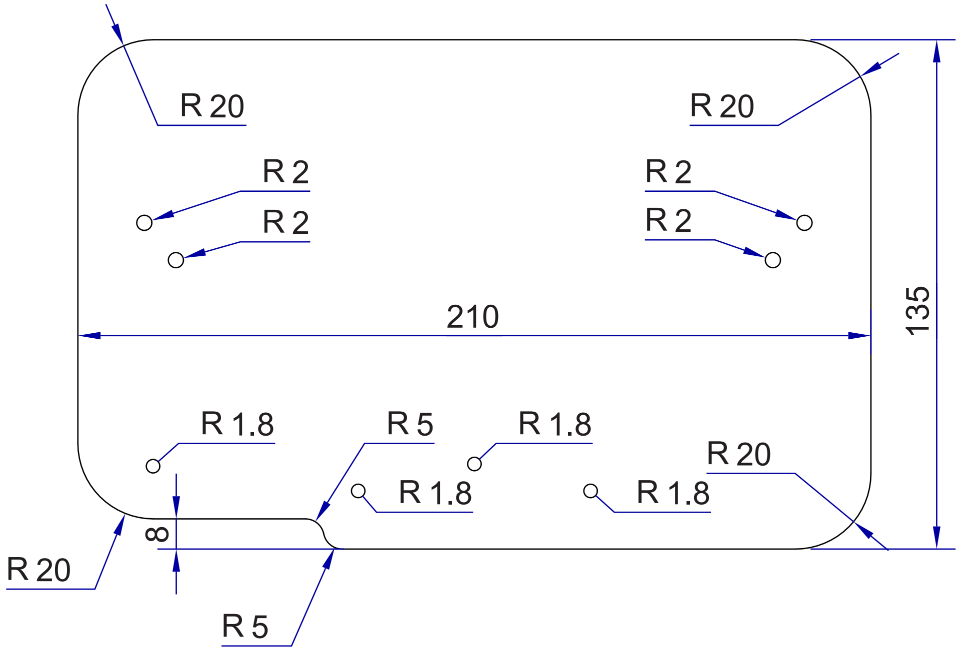
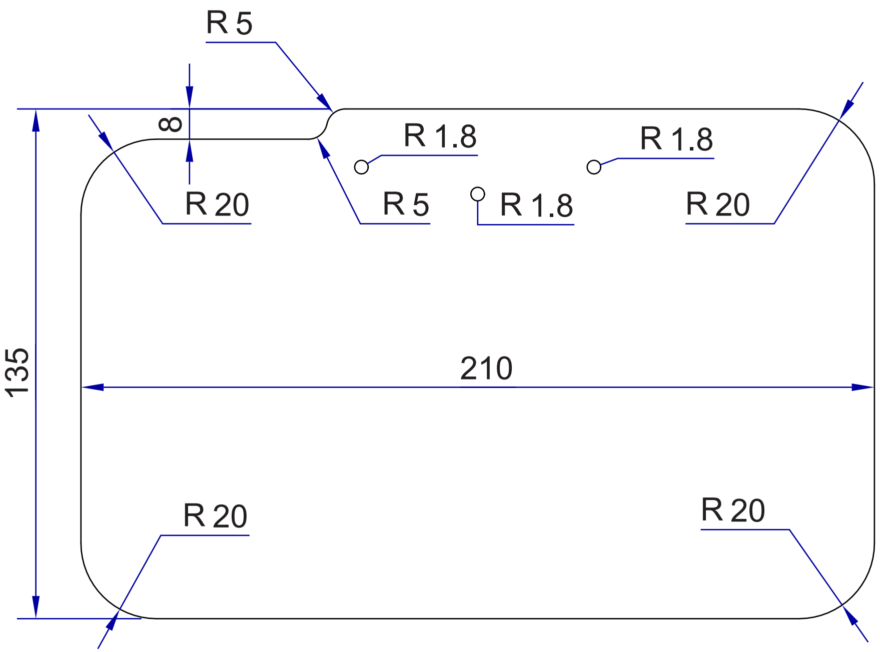
NOTE: All panel pieces laser cut from 1/8" HDPE plastic



TOP BACKBOARD PANEL



BOTTOM BACKBOARD PANEL

A4

ISO E

IronCAD
2D drawing
3D file available

Scale:
1:2 (mm)

General Tolerances acc to:
ISO 2768-1 medium

File Name:
MachineDrawingsNew.icd

Drawn by: NL

Checked by:

Approved by:

Last saved:
5/3/2014 11:24 PM

Created Date:
05/03/14

Team Nutriflow

Description

BACKBOARD OF BAG INVERTER ASSY.

Sheet No: 2 (2)

Rev. 2

Doc. No: **2**

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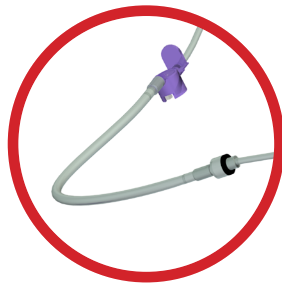
FLUID CIRCULATION LOOP CAD DRAWINGS

Our device recovers separated milkfat adhering to the tubing by periodically running milk at faster flow rates (10 mL/min) in a circulating fluid loop.

Pump driven flow rates

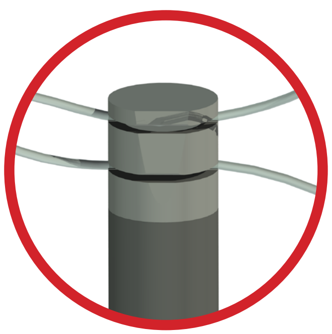
Ideally, Kangaroo enteral pump will integrate functionality to periodically alternate between fast and slow flow.**

**Current fast flow is driven by a second peristaltic pump (not shown), which is connected in series with the Kangaroo



Integration with Covidien Kangaroo ePump™

Commercially available **ePump™ rotor valve and tube** connects to the Kangaroo ePump™

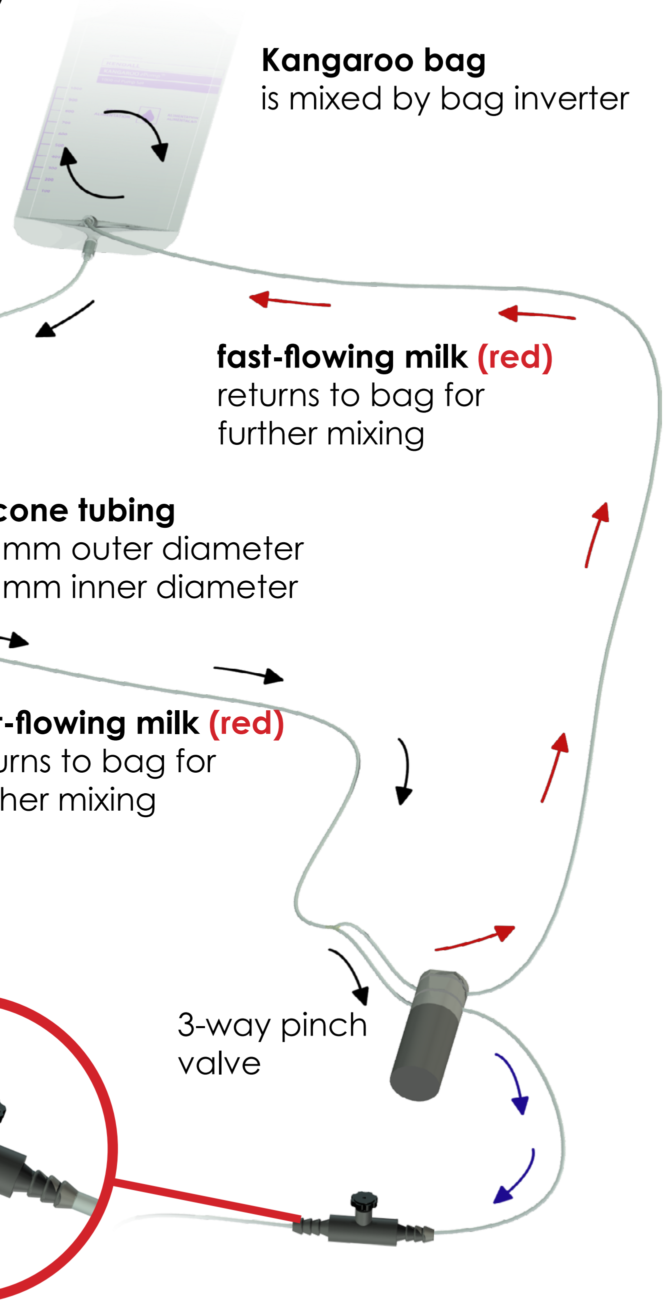


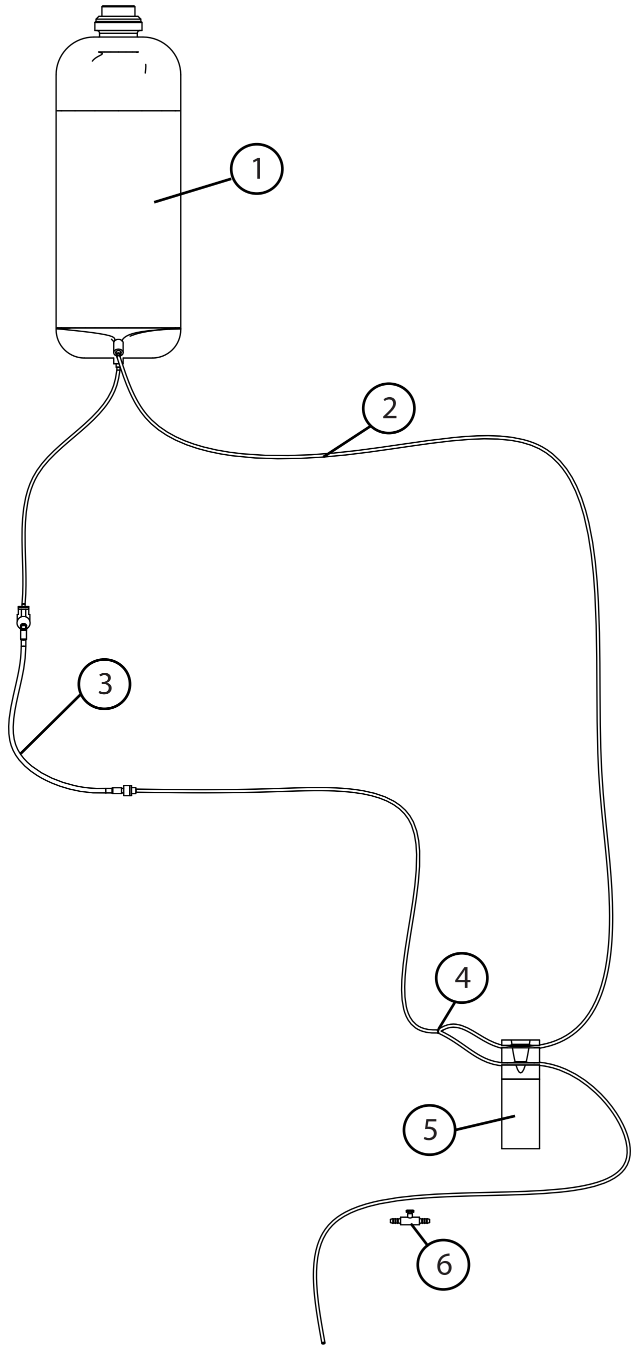
Minimal contact with milk

Bio-Chem Fluidics® 3-way pinch valve determines direction of flow based on flow rate

Safety valve for flow rate regulation

additional Hospira® low-flow regulator valve ensures only **slow-flowing milk (blue)** reaches neonate





BILL OF MATERIALS

PART NO.	QTY.	DESCRIPTION
1	1	Kangaroo Feed Bag
2	4 ft	Thermo Scientific[R] Sterilin[TM] 0.5 mm ID 1.2 mm OD tubing
3	1	Kangaroo ePump[TM] rotor valve and tubing
4	1	Ibidi[R] 0.5 mm flow splitter
5	1	Bio-Chem Fluidics[R] 3-way pinch valve
6	1	Hospira[R] IV Low Flow Regulator

A4 ISO E	IronCAD 2D drawing 3D file available Scale: 1:8 (mm)	General Tolerances acc to: ISO 2768-1 medium	File Name: CircLoopMachineDrawings.icd			Last saved: 5/4/2014 12:41 AM
			Drawn by: NL	Checked by:	Approved by:	Created Date: 05/03/14
Team Nutriflow			Description FLUID LOOP ASSY.			Sheet No: 1 (1) Rev. 1 Doc. No: 1

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APPENDIX C: Data/Testing and Results

I. Data

Final Prototype Testing in Triplicate with Milk Control, Milk with Prototype, Fortifier Control, Fortifier Prototype

Below are the results of the control tests:

Milk Control #1

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.4	2.9	2.7	2.8	2.2	3.4	64.71%
Protein	1.2	1.3	1.4	1.3	1.4	1.5	
Carb	7	6.7	6.9	6.7	7.3	5.9	
Cal	18.9	17.5	17.1	17.2	16.3	18.1	

Milk Control #2

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.8	3.3	2.6	2.6	2	3.2	52.63%
Protein	1.2	1.4	1.4	1.5	1.4	1.2	
Carbohydrates	6.8	6.8	6.9	7.3	6.9	6.4	
Calories/oz	20	18.6	16.9	17.6	15.4	17.8	

Milk Control #3

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.7	3.1	2.8	3	2.1	3.6	56.76%
Protein	1.2	1.3	1.5	1.4	1.3	1.5	
Carbohydrates	6.8	6.6	6.5	6.9	7.5	6.7	
Calories/oz	23.4	17.9	17.2	18	16.4	19.5	

Fortifier Control #1

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	4.6	4	4.1	4	2.9	4.1	63.04%
Protein	1.9	2	2	2.1	1.8	2	
Carb	6.5	7.7	7.8	7.4	7.8	7.6	
Cal	22.5	22.5	22.8	22.2	19.3	22.5	

Fortifier Control #2

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	5	4.3	4	3.8	2.4	3.4	48.00%
Protein	2	2	1.9	1.8	1.8	1.9	
Carb	7.3	6.9	7.4	7.3	7.2	8	
Cal	24.7	22.4	21.9	21.2	17.3	21.2	

Fortifier Control #3

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	4.9	4.3	4	4	3.4	4.3	69.39%
Protein	2.2	2.1	1.9	2.1	2	2.1	
Carb	6.2	6.8	7.1	6.5	7.5	7.5	
Cal	23.4	22.2	21.7	21.2	20.6	23.2	

Below are the results of the final prototype tests:

Milk Prototype #1

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.4	3.1	3	3	3	3.3	88.24%
Protein	1.3	1.3	1.3	1.3	1.2	1.3	
Carb	6.6	6.2	6.8	6.2	6.8	6.9	
Cal	18.7	17.4	18	17.1	17.6	18.7	

Milk Prototype #2

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.4	3.2	3.2	3.2	3.3	3.4	97.06%
Protein	1.2	1.3	1.4	1.4	1.5	1.4	
Carbohydrate s	6.3	6.7	6.7	7.1	6.8	6.3	
Calories/oz	18.1	18.1	18.4	18.9	18.8	18.6	

Milk Prototype #3

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	3.3	3.2	3	3.3	3.3	3.5	100.00%
Protein	1.3	1.3	1.2	1.3	1.3	1.3	
Carbohydrates	6.2	6.4	6.1	6.9	7.1	6.3	
Calories/oz	18	17.9	16.9	18.6	18.8	18.7	

Fortifier Prototype #1

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	5.1	4.2	4.3	4.4	4.3	5.2	84.31%
Protein	2.1	1.8	2	2.2	2	1.8	
Carb	7.3	6.8	6.7	7.1	7.7	7.4	
Cal	25.3	21.6	22	23.1	23.3	25	

Fortifier Prototype #2

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	5.1	4.2	4.5	4.7	4.3	4.5	84.31%
Protein	2	1.7	1.7	2	1.8	2	
Carb	7.7	6.5	6.8	7.4	6.7	6.7	
Cal	25.3	21.2	22.2	24.1	21.9	22.7	

Fortifier Prototype #3

Time (min)	0	15	30	45	60	60 bag	Fat Retained
Fat	4.6	4.4	4.3	4.3	4.2	4.6	91.30%
Protein	1.8	1.7	1.7	1.8	1.8	1.8	
Carb	7.2	7.8	7.5	7.1	6.5	7.2	
Cal	23.2	23.1	22.5	22.2	21.4	23	

APPENDIX C: Data/Testing and Results

II. Testing and Results

Testing

We conducted fat content, sound, and temperature tests to prove that our device retains a high percentage of the initial fat content and maintains NICU standards for current medical devices. By performing control tests in triplicate, we were able to compare the results of our device to the current system used in neonatal intensive care units.

Fat Content Testing

We tested the Nutriflow device the way it would be used in a standard NICU setting. After thawing the milk, pouring it into the feed bag, and priming the tubing, we turned on the device for a one hour feed while running the inversion and recirculation system simultaneously. One-hour feeds are most common for infants requiring tube feeding. We chose 20 mL/hr as the flow rate because this is a relatively slow flow rate and the common rate for premature infants. Due to the slow flow rate, there will be a low fat retention, and our results will show improvement for the situations where fat loss is severe.

Three control tests were performed with both breast milk and fortified breast milk. These control tests were compared to tests with our final prototype in operation. Control tests were performed exactly how they are currently performed in the NICU setting with the Kangaroo ePump™. Breast milk was thawed and poured into the bag and the Kangaroo ePump™. The pump ran for one hour at 20 mL/hour. Our final prototype tests were performed by operating the Kangaroo ePump™ in conjunction with our prototype. When fortifier was tested, Prolacta H^2MF was mixed in a 1:4 ratio of fortifier to milk.

Sound Testing

We conducted sound testing to ensure that the device's noise level was equivalent to other NICU devices, like the bCPAP. By measuring the sound during a typical feed with our device, our results are indicative of the true sound levels that would occur when the device is implemented. While the device was operating as it would in a typical feed, the sound level of the device was tested using a db-307 Noise Sound Level Meter. The tests were performed in a quiet room (below 20 dB) in order to ensure the accuracy of the tests.

Temperature Testing

We also conducted temperature testing to ensure that the device did not increase temperature above 25°C or risk protein degradation in the breast milk. The temperature of milk was measured with a mercury thermometer before and at the end of a one hour feed. We allowed 3 minutes for the thermometer to stabilize before recording the temperature. Both breast milk and fortified breast milk were tested three times each and the averages are recorded.

These tests demonstrate the effectiveness of our device. All conducted tests were formed under settings that actually mimic settings where our device would be implemented. The flow rate, milk preparation, and feed time all mimic typical settings. The control tests show a direct comparison of our device to the Kangaroo ePump™ that is currently used. Every test was performed in triplicate, and the low standard deviations confirm that the data is meaningful ($p<0.005$ for expressed breast milk and $p\leq0.060$ for fortified breast milk).

Results

Fat Content Results

A full data set of the results can be found in Appendix D.I. The first graph below displays the average fat retained over time with breast milk (Figure 1,2). The blue line represents our device and the red device represents the control. The second graph below displays the results of the fortified milk control compared to our device tested with fortified milk.

NUTRIFLOW DEVICE INCREASES FAT RETENTION FOR BREAST MILK

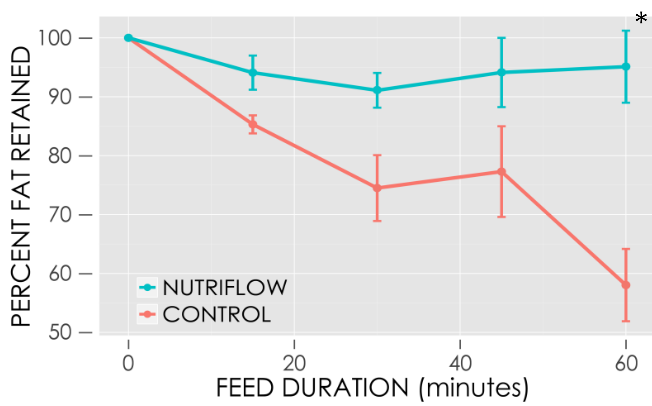

Figure 1. Nutriflow device increases the fat retained in breast milk over a 1 hour feed from 58% to 95%. *p<.0005

NUTRIFLOW DEVICE INCREASES FAT RETENTION FOR FORTIFIED BREAST MILK

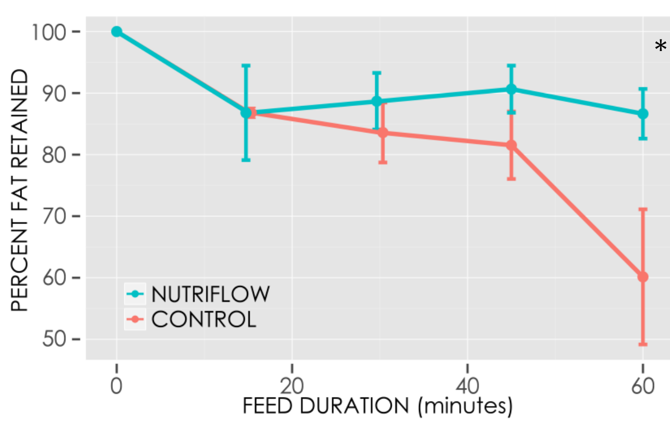

Figure 2. Nutriflow device increases the fat retained in fortified breast milk over a 1 hour feed from 60% to 88%. *p<.06

Our results show that the Nutriflow device significantly increases the fat that is delivered to infants for both expressed breast milk and fortified breast milk. By combining inversion of the bag and recirculation of milk in the tubing, we are able to prevent the fat from separating and adhering to the bag and tubing.

Sound Results

These results shown in Table 1 illustrate that our device is quieter than most bubble CPAP systems, which are commonly used in neonatal intensive care units. For example, common bubble CPAP noise levels are 83 dB, 72 dB, 62 dB, and 55 dB[1].

Table 1. Sound testing shows that device fits within constraints of NICU noise levels.

Status of Device	Noise Level (dB)
Motor and priming features OFF	45.8
Motor ON	54
Prime ON	59
Motor and priming features ON	59

Temperature Results

These results shown in Table 2 show that our device does not significantly change the temperature of the milk. The inversion and recirculation system are gentle and have no effect on temperature.

Table 2. Temperature of milk using the Nutriflow does not exceed 25°C

Fluid Type	Average Temperature (Before)	Average Temperature (After)
Breast milk	25.0° C	24.7° C
Fortified breast milk	24.2° C	24.3° C

NURSE SURVEY

Our team also surveyed 13 nurses and physicians from Neonatology at Baylor College of Medicine and Texas Children's Hospital. Each participant was given a 3-minute explanation of the device's function and its operation, and then asked to complete a short survey estimating additional set-up time required and their comfort in operating our device, as well as questions prompting feedback for improving the ease of use or safety of our device.

The survey results indicated users estimated an average of ~2.5 minutes of additional setup time per feed required to operate our device over the current standard of care. On a scale from “very uncomfortable” to “very comfortable” operating our device following our demonstration, all survey responses indicated users would be “comfortable” or “very comfortable”. From qualitative feedback given, the biggest point of improvement for our device was increasing the length of tubing between the 3-way valve separating the fluid circulation loop and the neonate. Given that this length of tubing cannot be mixed by recirculation in our current device, it will be important to find a compromise between fat retention and tubing length.

Reference

1. Kirchner, Lieselotte, Martin Wald, Valerie Jeitler, and Arnold Pollak. "In Vitro Comparison of Noise Levels Produced by Different CPAP Generators."Neonatology 101.2 (2012): 95-100. Print.

APPENDIX D: Other Relevant Information

I. Design Criteria

CRITERIA	TARGET	MEASUREMENT	RATIONALE
Fat Retention	Deliver >80% of the fat content in unsupplemented breast milk to the infant	Milk content IR spectroscopic analysis using Unity Scientific Spectrastar™. Time-resolved data will ensure reduction of nutrient loss for the entire duration of a 1-hour feed.	Fat delivery is essential to infant growth and development. In addition to serving as major source of calories, fat also carries proteins and mineral nutrients important for immunologic and neurologic development (Underwood et al.)
Cost	One-time use components should cost <$15.00, and fixed reusable components <$300.	Sum the costs of individual device components.	The cost of our device determines implementation and market share capture, and should be comparable to the cost of current standards of care. The current Kangaroo ePump™ costs $500 and uses disposable feedings bags priced at $6.50. Given the increased benefit of nutrient delivery, our mentors at BCM suggested $15/use for disposable components.
Sterility	No device components beyond bag/tubing should not physically come in contact with breast milk	In order to maintain sterility, the design will not allow milk in the bag/tubing to come into contact with any object outside of the device.	All products in the NICU need to be easily sterilized in order to prevent infection in high-risk infants.
Temperature	The temperature of the breast milk in the bag and the tubing cannot exceed 40° C at any point in the feed.	This will be measured using a thermometer at 3 different time points during a 1 hour feed.	Bioactive and immune proteins in breast milk (IgE) preserve their activity when the temperature of the breast milk does not exceed 40°C [10].
Noise level	The device should not introduce >80 dB of noise into the NICU.	We will measure the noise of the device in a quiet room, using a db-307 Noise Sound Level Meter.	Most NICU's exceed the recommended noise level of 45 dB[11]. Our team measured that continuous positive airway pressure (CPAP) devices produce an average of 80 dB of noise, and sit at a similar proximity to the neonate compared to our device.
Ease of Use	Add <5 minutes to set-up and operation of the pump during a 1 hour feed	Surveying nurses and other users at Baylor and Texas Children's Hospital to estimate the time of set up for the device and start a simulated feeding.	Five minutes added to an approximately 20 minute existing set-up was chosen because it should not disrupt the normal function of the NICU.
Safety and FDA approval	Minimize biological, electrical, physical risks and satisfy requirements for FDA class II medical devices.	The safety of the device will be evaluated according to FDA guidelines for class 2 medical devices.	FDA approval of our device will be required for implementation in hospital settings. We must not introduce any hazardous materials or risk of electric shock to the infant.

APPENDIX D: OTHER RELEVANT INFORMATION

II. Cost Analysis

COST OF REUSABLE COMPONENTS

Part*	Quantity	Unit Price	Scaled Low Quantity Cost	Bulk Volume Cost
Texas Instruments® MSP430 Microcontroller	1	$10.41	$10.41	$2.60
Custom printed circuit board (Sunstone Circuits®)	1	$1.84	$72.13†	$1.70
Takamisawa JV-3S-KT DC Relay	2	$1.75	$4.98	$1.75
Custom HDPE encasing for circuitry	1	$2.00	$2.00	$1.00
12 V DC Motor (Shenzhen Motor Co.)	1	$8.20	$10.00	$3.49
12 V dosing peristaltic pump (GHH Co.)	1	$14.95	$14.95	$3.74
Biochem Fluidics® 3 way 2.2 mm pinch valve	1	$80.20	$80.20	$20.05
Twixit® Bag Clips	2	$2.68	$5.36	$4.20
Black 1/8" HDPE Laser Cut backboard panels	2	$1.00	$2.00	$0.50
Clear 1/4" Acrylic guard panels	2	$1.50	$3.00	$0.50
Hillman Group® Steel 1" corner braces	2	$2.36	$4.72	$2.00
#5-40x1/2" screw (Zoro®, Fastenal®)	18	$0.05	$0.90	$0.50
3/4" x 3" Velcro® Strips	1	$1.00	$1.00	$0.25
Everbilt® 5/8" Door Hinge	2	$2.78	$5.56	$2.00
Everbilt® 1/4"x3" zinc-plated screw hook	1	0.62	$0.62	$0.05
IV Pole Attachment 2" length 3" diam. PVC	1	$2.50	$2.50	$0.50
Total cost of components	**–**	**–**	**$220.33**	**$44.83**
Estimated assembly cost‡	–	–	–	$3.69
Quality Assurance	–	–	–	$20.00
TOTAL	**–**	**–**	**–**	**$68.52**

* If no manufacturer listed, part is machined/altered in-house

† Sunstone Circuits provides a costly 2-day turnaround service for prototyping

‡ Assuming $0.07/connection for circuit board parts, and ballpark estimates for manufacturing assembly

COST OF DISPOSABLE COMPONENTS

Part*	Quantity	Unit Price	Scaled Low Quantity Cost	Bulk Volume Cost
Goodfellow 0.5 mm ID Silicone Tubing	1.21 m	$7.50/m	$9.07	$1.13
Ibidi Polypropylene "Y" Tube Fitting 0.8 mm ID	1	$2.24	$2.24	$0.28
Hospira IV Flow Regulator	1	$0.75	$0.75	$0.13
DEHP-free Polyurethane 1000 mL feed bag	1	$4.18	$4.18	$0.52
Total cost of components	**–**	**–**	**$16.24**	**$2.06**
Estimated assembly cost	–	–	–	$1.00
Quality Assurance	–	–	–	$1.00
TOTAL	**–**	**–**	**–**	**$4.06**

* If no manufacturer listed, part is machined/altered in-house