Proposed Design for the Potential of Recovering Useful Products from Farm Animal Waste

The world population is currently about 6 billion people. It has been mathematically proven that population doubles every 40 years. Ten years from now, there will be more people living on the earth than the sum of all people that have died throughout history. What does this mean? Basically, with so many people living, there is going to have to be an increase in the amount of food produced so the earth can sustain life. According to many agriculturalists, this increase can only be met by increasing the number animals raised for food.

There is one major problem with this simple solution. Most farms already have far more waste created by the present amount of animals than they are able to dispose of. Therefore, in order to maintain life on this planet, something has to be done to the manure that is going to be created. Research has been concluded for solving the problem of excess animal waste from large farms. The two processes of animal waste utilization that were analyzed and designed are Anaerobic Digestion & Lagoons and *The Stiller Process.* After analyzing all of the researched information, as well as lab generated data, final designs has been completed for both processes. After completing experimentation and calculations, *The Stiller Process* has been found to be more profitable than existing methods normally used on the farms. It has been concluded that *The Stiller Process* could potentially replace the existing systems and in turn, improve the quality of everyday life.

Two different scenarios investigated for the design of the stiller Process. Both systems contained similar feed and reactor systems. The more profitable one, which had a BEP of $0.46/gal of reactor product shipped all reactor products off-site. The other system had additional separation sections that drove up the costs. It had a BEP of about $0.75/gal of reactor product.

ANAEROBIC DIGESTION & LAGOONING

RESULTS

LAGOONING

The design for anaerobic lagoons and digesters for use with each type of manure being studied began with a research phase and was followed by the sizing of the anaerobic lagoon. Figure 1 shows the layout for a typical lagoon.

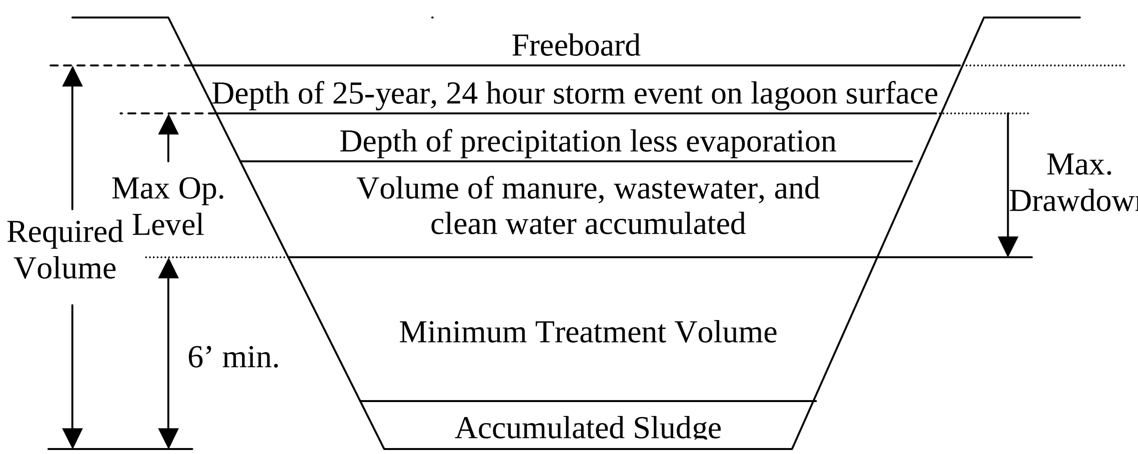

Figure 1: Basic Lagoon Configuration

Accumulated sludge or sludge volume (SV) represents the amount of non-digested material consisting primarily of minerals and residue like substances that will accumulate between sludge removals. Minimum treatment volume is the volume needed to sustain biological activity. The combined depth of the accumulated sludge and minimum treatment volume must be a minimum of 6 ft. This level represents the maximum drawdown for the lagoon, or the amount left after dewatering where anaerobic activity can be expected. The volume of manure, wastewater, and clean water accumulated (WWV) reflects the volume of manure, wastewater, flush water that will not be recycled, and clean dilution water.

Depth of precipitation less evaporation is an estimation of additional storage due to rainfall. The depth from a 25-year, 24-hour storm event is an estimation of additional storage needed in the event of a massive storm, which on average occurs once every 25 years for a 24-hour period. For Hardy County, WV, where the farm is located, this number was found to be 5.5 in [3]. Finally, freeboard is an additional volume added to ensure that the lagoon will not overflow. A standard minimum is 1.0 ft.

Figure 2 shows the layout for a two-lagoon system, which would be used for poultry manure. This is a two-stage system in which the excess from the first lagoon spills into the second. The water in the second lagoon is clean and can be recycled back to the houses. The recycle will be used to dilute the litter before it enters into the first lagoon as well as aid in the flow of the waste to the lagooning area.

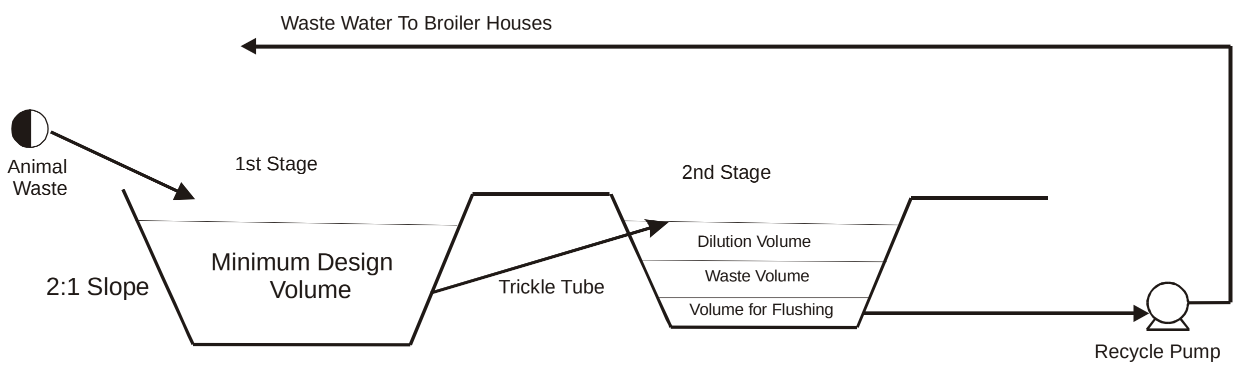

Figure 2: Two-Stage Lagoon System for Poultry Manure

Table 1 summarizes the results of the calculations for each type of manure. Poultry requires a two-lagoon system, and the secondary lagoon is 75% of the size of the first lagoon [1]. The adjusted volume shown in Table 1 represents the addition of precipitation less evaporation, depth from the 25-year, 24-hour storm, and freeboard. For a poultry lagoon, the second lagoon eliminates the need for added depth, as the total volume of the combined lagoons is slightly larger than the requirements for a single lagoon. The poultry lagoon is much larger than the others due to the addition of paper and sawdust that is used as chicken house bedding.

Table 1: Summary of Lagoon Sizing

Animal Type	Beef	Dairy	Swine	Poultry-1	Poultry-2
Animal Weight (lb)		1000	150	2	2
Number of Animals	00	500	3,000	220,500	220,500
Waste volume (ft^3)	13,000	1,380,000	81,000	562,800	422,100
Sludge Volume (ft^3)	,500	65,680	505,000	162,000	121,500
Minimum Lagoon Volume (ft^3)	70,000	1,447,000	1,072,000	--	--
Adjusted Volume (ft^3)	97,000	1,865,000	1,475,000	6,077,000	4,557,750

The only costs to construct the lagoons are the costs of excavation and a liner in the ground to prevent seepage into the ground, as shown in Table 2.

Table 2: Summary of Costs of Lagoon Construction

	Dairy	Swine	Beef	Chicken
Excavation Costs	$ 120,900	$ 96,270	$ 187,800	$ 689,300
Liner Cost	$ 666,000	$ 558,700	$ 1,121,000	$ 2,651,000
Total	$ 786,900	$ 654,900	$ 1,309,000	$ 3,341,000

<u>ANAEROBIC DIGESTION</u>

Anaerobic digestion was next researched, and digesters were designed for all types of manure. Figure 3 shows an anaerobic digester with a power generation system. As shown in Figure 3, the biogas generated is passed through a sulfide scrubber and purified before entering the engine/microturbine system for combustion and power generation. A heat integration loop has been implemented to utilize excess heat given off during the combustion process. Cooling water is used as coolant. After removing heat from the engine, the cooling water is then used to maintain the digester temperature at approximately 39.4°C and maintain the manure in the storage vessel at 26.7°C. Any remaining excess heat is then removed by passing it to the hot water tank to provide hot water for the farm. The heat integration loop shown is equipped with a system of controllers and temperature indicators that will allow for operation of the digester system without constant oversight.

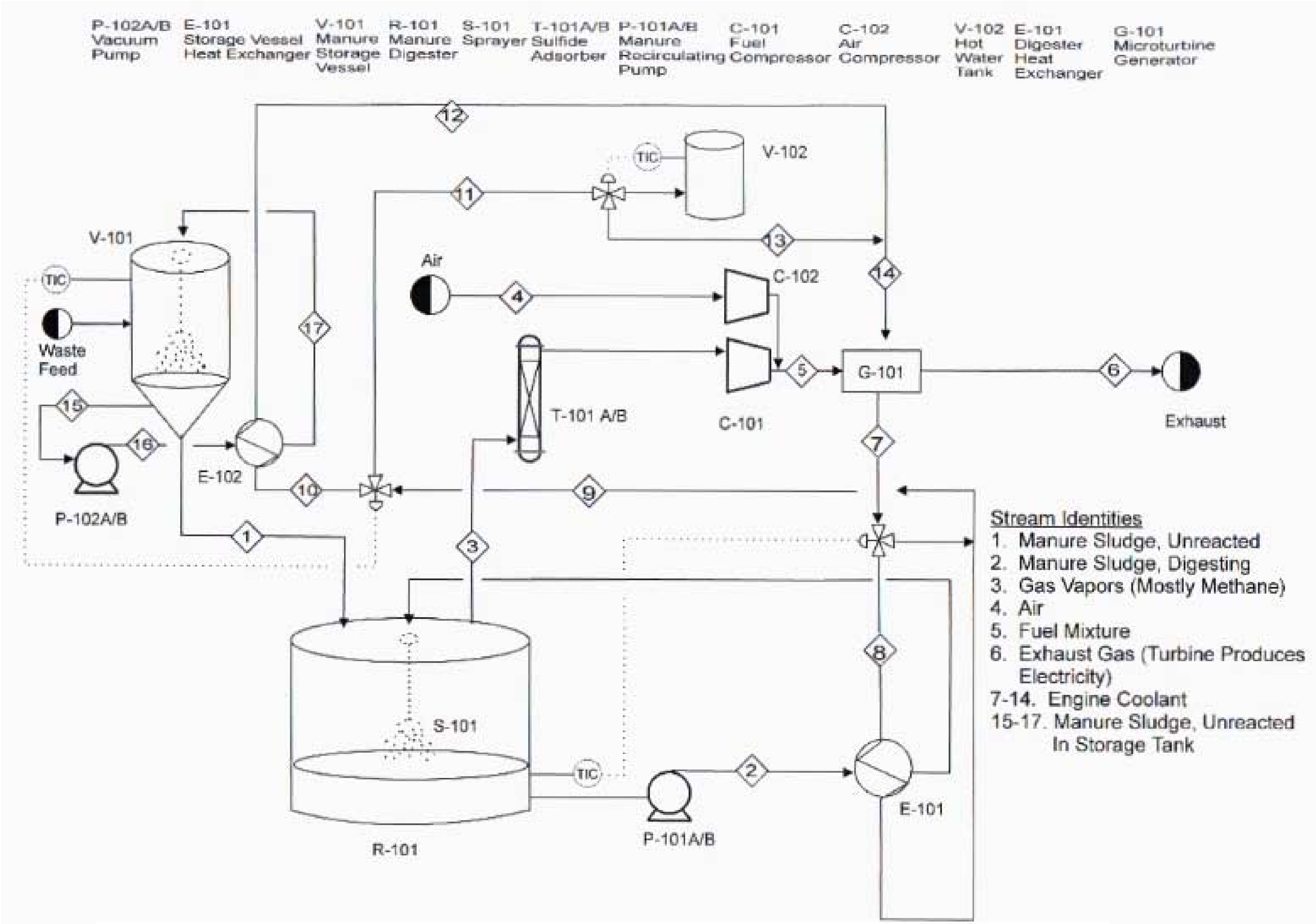

Figure 3: Chicken Manure Digester Coupled with Power Generation and Heat Integration

Table 3 summaries the results of the digester sizing. As expected, beef cattle, dairy cattle, and swine manure require similar volumes for digestion. Poultry manure requires more volume for dilution due to the high solids content of the manure.

Table 3: Summary of Digester Sizing

Dimension	Beef	Dairy	Poultry	Swine
Depth (ft)	11.42	11.57	15.33	10.57
Width (ft)	22.84	23.15	30.66	21.15
Length (ft)	45.68	46.29	61.31	42.28
Total Volume (ft^3)	12,820	13,350	31,300	10,160

Following digestion, manure sludge must be stored before being applied to the land as fertilizer. For this purpose, storage lagoons were designed. These lagoons are similar to the lagoons designed above; however, they require a much smaller volume as a much larger amount of manure is degraded in the digestion process. A summary of this sizing is shown in Table 4.

Table 4: Summary of Finishing Lagoon Sizing

	Dairy	Chicken	Swine	Beef
Bottom Width (ft)	100	190	100	120
Bottom Length (ft)	46	75	50	55
Depth (ft)	16.12	16.12	14.12	14.12
Volume (ft^3)	172,500	390,000	145,500	106,300

Costs of a digestion system are summarized in Table 5. The storage tank for each type of manure is similar in cost to the digester vessel, as a similar retention time of twenty days is assumed. Insulation is necessary to keep the digester up to temperature during the colder months, while heat exchangers are needed to supply heat to the digester and storage tank to raise the temperature of the manure to digestion temperature. Agitation systems are necessary to keep the digester well mixed and prevent the formation of a crust at the top of the digester and a cover is needed to collect gases from the digester. Costs of finishing lagoons include excavation and a liner.

Table 5: Summary of Costs of Digester Construction

Component	Beef	Dairy	Chicken	Swine
Storage Tank	$ 24,640	$ 25,410	$ 60,470	$ 20,650
Digester Vessel	$ 24,640	$ 25,410	$ 48,590	$ 20,650
Insulation	$ 1,592	$ 1,635	$ 3,496	$ 1,363
2 Agitation Systems (+ necessary pumps)	$ 18,000	$ 18,000	$ 18,000	$ 18,000
Heat Exchanger for Digester	$ 5,227	$ 5,418	$ 10,870	$ 5,300
Heat Exchanger for Storage Tank	$ 4,960	$ 5,141	$ 5,377	$ 5,023
Digester Cover	$ 139,000	$ 142,500	$ 205,000	$ 129,000
Sludge Lagoon Excavation	$ 11,540	$ 11,180	$ 25,280	$ 9,431
Lagoon Liner	$ 53,070	$ 44,640	$ 101,700	$ 43,190
Total	**$ 282,700**	**$ 279,300**	**$ 478,800**	**$ 252,600**

POWER GENERATION FROM BIOGAS PRODUCTION

Both lagoons and anaerobic digesters produce significant quantities of biogas. The possibility of using microturbine generators to burn the biogas produced was investigated. A summary of additional costs for power generation from lagoon biogas is shown in Table 6. The greatest cost is a cover for the lagoon to collect the gas. After the cover and generator, the remaining costs are associated with a system to remove hydrogen sulfide from the biogas.

Table 6: Summary of Costs of Lagoon Power Generation

	Dairy	Swine	Beef	Chicken
Cover Cost	$ 609,800	$ 485,300	$ 1,005,000	$1,352,000
Engine Generator Cost	$ 120,000	$ 80,000	$ 55,000	$ 400,000
Sulfide Filter	$ 39,680	$ 39,680	$ 39,680	$ 39,680
H_2S Monitor (calibrated)	$ 7,500	$ 7,500	$ 7,500	$ 7,500
Media Replacement/ year	$ 6,000	$ 6,000	$ 6,000	$ 6,000
Total Cost of System	**$ 782,900**	**$ 618,500**	**$ 1,113.000**	**$ 1,805,000**

Table 7 summarizes the costs for a power generation on the biogas from digesters. Costs are similar to the costs of power generation for lagoon biogas.

Table 7: Summary of Costs of Digester Power Generation

Component	Beef	Dairy	Chicken	Swine
Vacuum Pump	$ 1,000	$ 1,250	$ 1,000	$ 1,000
Engine Generator	$ 40,000	$ 50,000	$ 75,000	$ 45,000
Sulfide Filter	$ 39,680	$ 39,680	$ 39,680	$ 39,680
H_2S Monitor (calibrated)	$ 7,500	$ 7,500	$ 7,500	$ 7,500
Media Replacement/ year	$ 6,000	$ 6,000	$ 6,000	$ 6,000
Total	**$ 94,180**	**$104,420**	**$129,180**	**$ 99,180**

To evaluate the profitability of using generators, net present values were calculated for lagoon and digester systems as shown in Tables 8 and 9, respectively. The value of energy produced was estimated at $0.06/kWh [2]. Incremental net present values were calculated for power generation. Since incremental net present values are negative for all lagoons as shown in Table 8, power generation is not recommended.

Table 8: Summary of Economics for Lagoon Power Generation

	Beef	Chicken	Dairy	Swine
FCI Lagoon	$1,309,000	$3,341,000	$786,900	$654,900
FCI Power Generation	$1,113,000	$1,805,000	$782,900	$618,500
FCI Total	$2,421,000	$5,146,000	$1,570,000	$1,273,000
kWh Generated	72,270	468,800	130,900	91,240
Energy Value ($/kWh)	$0.06	$0.06	$0.06	$0.06
Annual Revenue	$4,336	$5,474	$7,856	$28,130
NPV Lagoons Alone	-$1,309,000	-$3,341,000	-$786,900	-$654,900
INPV Power Generation	-$1,091,000	-$1,664,000	-$743,500	-$591,000

Table 9 shows that power generation will only be profitable for chicken and dairy cattle manure. In Table 9, the value of heating is an estimation of the value of the heat from the generator used to heat the digester and storage tank. This value was assumed to be equal to $3.17/GJ, the value of low-pressure steam [2]. Therefore, power generation is recommended for only chicken and dairy manure.

Table 9: Summary of Economics for Digester Power Generation

	Beef	Chicken	Dairy	Swine
FCI Digester	$282,700	$478,800	$279,300	$252,600
FCI Power Generation	$94,180	$129,180	$104,420	$99,180
FCI Total	$376,900	$607,900	$383,800	$351,800
kWh Generated	192,200	731,300	347,500	238,400
Energy Value ($/kWh)	$0.06	$0.06	$0.06	$0.06
Value of Heating	$1,403	$5,338	$2,537	$1,740
Annual Revenue	$11,530	$43,880	$20,850	$14,300
NPV Digesters Alone	-$289,700	-$505,600	-$292,100	-$261,300
INPV Power Generation	-$29,300	$117,800	$12,950	-$18,640
NPV with Power		-$387,700	-$279,100	

RESULTS

The *Stiller Process* for converting animal waste into usable substances is a new technology that is in the research and development stage. Thus far, only laboratory-scale experiments have been preformed. The results of these experiments have revealed the optimal operating points for this process. The optimal operating points are defined as the specific reaction conditions that produce the most products from the reaction. The product that the system was optimized for was the acetone cut. The optimal mass ratio of litter to water is 0.87 mass units. The optimal temperature is 355°C with a curing time of 23 minutes.

It is known that water and animal waste, be it poultry, swine, or bovine litter, are blended together, and heated. The reaction is run at high temperatures, 330-370°C, and high pressures, approaching 3600 psi. At these conditions, it is hypothesized that water breaks down into hydrogen and hydroxide radicals. These radicals react with the animal waste to produce three substances: a diesel fuel additive, an aqueous phase with various organic chemicals, and a gas. The solid product is then differentiated into three separate cuts; material soluble in diesel fuel, material soluble in acetone, and material soluble in neither. The specific identities of the reactants and products are unknown at this time, as is the exact mechanism of the reaction. The block flow diagram for the *Stiller Process* is shown in Figure 4.

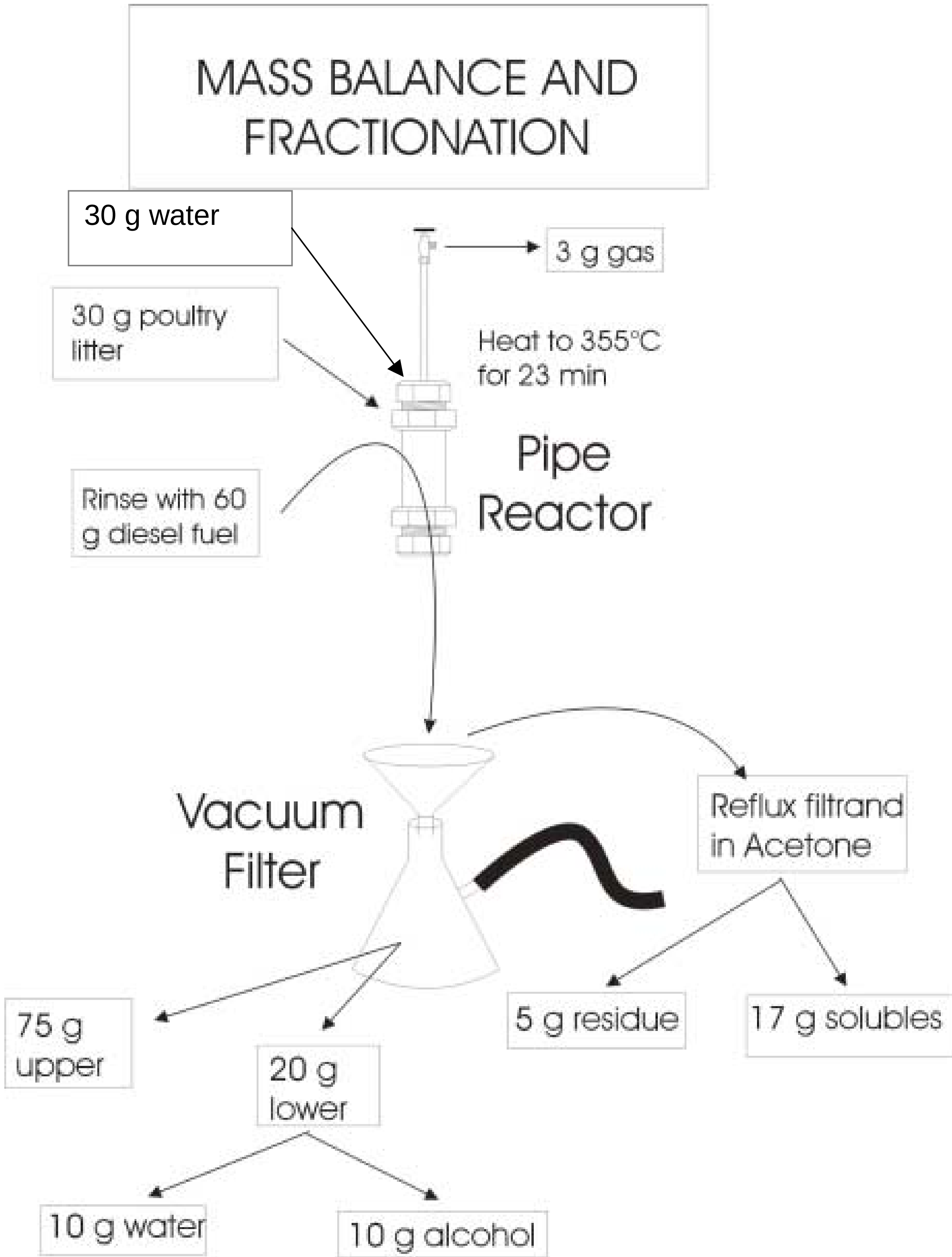

Figure 4: Stiller Process Mass Flow Chart

RESULTS

ON-SITE REACTOR WITH OFF-SITE SHIPPING

The PFD for this process is shown in Figure 5. The process chicken litter is fed through a grinder and then to a hopper above the reactor where it is mixed with water to obtain the desired consistency. The rotating screw extrudes the mixture from the hopper and sends it into the first chamber (piston 1 is up and piston 2 is closed) until the chamber is full. Once the chamber is full, piston 2 opens and piston 1 presses the mixture down into chamber 2. With piston 1 still closed, piston 2 compresses the mixture into the reactor pipe. The pipe itself is surrounded by a heating source. While piston 2 is compressing the mixture into the reactor pipe, the final pressure release piston is closed. It is known that a substantial amount of gases is produced in the reaction, which allows compression to be easily obtained. As the reaction is occurring, piston 1 rises again and chamber 1 is refilled. As pressure builds in the reactor, the pressure release piston is pushed back, and the products are pushed out into the decompression chamber while the gases are released through the vent. Once the products are gathered, the pressure release piston is closed again, while at the same time, piston 2 pushes a new load of feed into the reactor from the opposite end. The *Stiller Process* is set up to be a continuous batch process that must be timed so that everything runs together smoothly.

It was determined that in order to achieve the desired curing time of 23 minutes, the reactor for this process needs to be 72 feet long with a diameter of 2.5 inches. In addition, because of the high pressures that this reaction achieves, a wall thickness of 0.84 inches is needed for stainless steel construction. Another constraint given was that the ratio of animal waste to water had to be 0.87. This was determined by the experimental section to be a very important parameter to achieve the desired reactants, so water needs to be added to the chicken

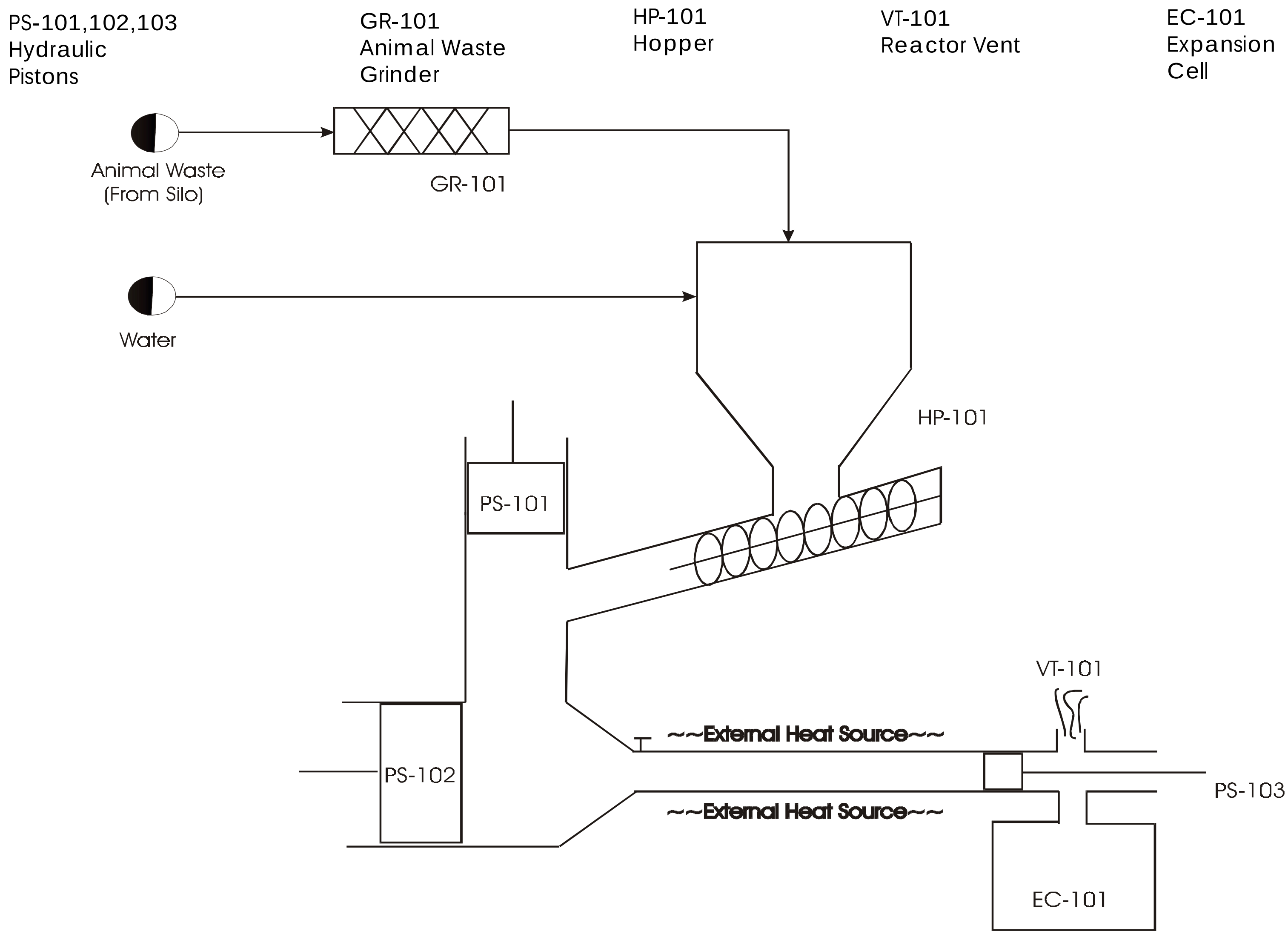

Figure 5: Reactor Design for *Stiller Process* (Continuous Batch)

litter before entering the reactor to achieve this concentration. It was determined that exactly 9.7 kg/h of water needs to be mixed with the chicken litter in the hopper before being fed to the reactor. This will produce mixture that is approximately 53.5% moisture.

The costs associated with this process are shown in Table 10. These costs contributed to the decision to use a heat pipe, where Dowtherm A is vaporized by using a furnace in order to supply the desired energy to the system. The reasons for choosing a heat pipe for the reactor, as well as the choice for using a furnace instead of an electric coil, are discussed further in the discussion section of this report.

Table 10: Equipment and Operating Costs for *Stiller Process*

EQUIPMENT COSTS					
Feed Section				**Unit**	
			Quantity	**Price**	**Total**
Cylinder #1	2500 psi		1	$ 117.99	$ 117.99
Cylinder #2	3000 psi		1	187.99	187.99
Tanks	4.8 gal		2	49.99	99.98
Engines	8 hp		2	539.99	1,079.98
Pumps	3600 psi		2	209.99	419.98
Soleniod Valves	4500 psi		2	139.99	279.98
Hoses	Various sizes & Diameter		8	12.99	103.92
Hopper			1	$28,000	28,000.00
					$30,289.82
Reaction Section					
95' of stainless steel pipe		per ft		3.9	371.00
Dowtherm A		per lb		2.29	67.84
storage tanks (agitated)			5	18,500	92500.00
Furnace				8,380	8380.00
					$101,318.84
				FCI	**$131,608.66**
				FCI (adjusted)	**$394,825.97**
YEARLY COSTS					
Natural Gas		$/GJ		$2.50	941.00
shipping					33600.00
				Yearly Costs	**$34,541.00**

As Table 10 shows, the largest costs associated with this process are the five agitated storage tanks and the cost of shipping. The fixed capital investment for this process was calculated to be approximately $130,000. This was then multiplied by a Lang factor of 3 to take into account installation and associated equipment. The cost of shipping the products dominates the yearly costs because there is only a very small amount of energy that needs to be put into this system. This will also be discussed in detail in the discussion section. Based on this data, a break-even price (BEP) for the reaction products was calculated. It was found that when using a 15% rate of return over a 10 year period before taxes, the crude reaction products would have to be sold at $0.467 per gallon to break even after ten years of operation. Because diesel fuel has an approximate value of $1.00 per gallon, *The Stiller Process* has the chance to be very profitable**.**

ON-SITE REACTOR WITH SEPARATIONS

Another option with the design of the Stiller Process was a unit that had simple on-site separations. The entire process has a fixed capital investment of $556,000 without the acetone fuel step, and $894,000 with the acetone step. A complete equipment summary can be seen in Table 11, which is also broken up into the separate sections of the process. For the total weight of products, including diesel solubles, solid product, and liquid product, the process must generate $0.74/gal or $0.09/lb in order to have no net losses over a ten year period, assuming a 15% rate of return. If we include the acetone solubles, the price rises to $1.16/gal or $0.14/lb. If the products can be sold or consumed on-site to generate savings above this rate, the process is profitable. However, it is important to note that if this process produces more product than the farmer himself can use, a means of transportation must be investigated to take the products to where they would be used, which adds additional costs not shown in this case.

Lastly, the overall size of this process was examined. The largest units in the process are the hopper and tanks. Assuming and L/D ratio of 3, the recycle and wash tank are both approximately 6 ft in length and 2 ft in diameter. The reactor effluent tank is 1.5 ft in diameter and 5 ft long. If all tanks are placed on a trailer vertically, there should be room beside the units to install the feed system, reaction system, and corresponding piping. The entire unit should not be more than 10 ft long since most units can be placed adjacent to the main tanks. The width and height should be acceptable to travel on roads without being a hazard. Ideally, the whole unit should approximate the size of a small RV.

Tabe 11. Equipment Summary

Equipment	Case 1*		Case 2**	
	Size	Cost	Size	Cost
Pump	1 GPM	$ 85	1 GPM	$85
Motor	5HP	$ 115	5Hp	115
Valve x4	Solenoid	$ 140	Solenoid	140
Jack	3600psi	$ 192	3600psi	192
Hopper		$ 2,500		2,500
Auger		$ 1,000		1,000
Grinder		$ 12,000		12,000
Valve	1" X 3/4"	$ 1,521	1" X 3/4"	1,521
Centrifuge	P 600	$ 100,000	P 850	200,000
D.F. Feed Tank	25.43 m^3	$ 5,511	25.43 m^3	5,511
Acetone Storage Tank	---	---	25.43 m^3	5,511
Liquid Storage Tank	5.8 m^3	$ 1,083	5.8 m^3	1,083
Diesel Fuel Feed Tank	26.8 m^3	$ 7,115	26.8 m^3	7,115
Solid Storage Tank	5.8 m^3	$ 1,083	5.8 m^3	1,083
Acetone Storage Tank	---	---	26.8 m^3	7,115
TK-102 (Recycle Tank)	0.65 m^3	$ 418	0.65 m^3	418
Washing Tank	0.65 m^3	$ 418	0.65 m^3	418
Reactor Effluent Storage Tank	0.21 m^3	$ 137	0.21 m^3	137
Impeller and Pump for Effluent Tank	5 HP	$ 9,894	5 HP	9,894
Impeller and Pump for Wash Tank	2 HP	$ 7,449	2 HP	7,449
Boiler	14.5 kW	$ 10,012	14.5 kW	10,012
Reactor	92 ft	$ 8,000	92 ft	8,000

Total Equipment= $ 168,673 $281,299

Estimated Fixed Capital Investment=*** $ 506,019 $843,897

*--Case 1 has no acetone separation.
**--Case 2 has acetone separation
***--Based on Lang Factor of 3.