Economic Analysis of Recycling Chiller Water in Poultry-Processing Plants Using Ultrafiltration Membrane Systems

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The poultry industry, one of the most important agribusiness industries in the United States, is facing multiple water-usage problems. These problems stem from rising water and sewer charges and an increase in pollution regulations. One way to reduce water usage and volume of wastewater is through internal recycling. Food scientists and applied economists at the University of Georgia are collaborating to evaluate the operational and economic effectiveness of polymeric ultrafiltration membrane technology at poultry processing plants. On-site tests of membrane system are underway, and preliminary economic analysis indicates highly positive prospects for this technology.

Poultry production is very important in the United States. Economically efficient technological breakthroughs are essential to maintain its competitive edge in processing and marketing. The Census of Manufacturers (1997) reports 260 companies engaged in poultry slaughtering. These companies own or operate 470 facilities, employ 224,000 employees, and produce about $32 billion of shipments annually. This industry is highly concentrated in the southeastern states. In Georgia, it represents the largest agricultural industry, with an annual contribution to the economy of $2.2 billion in 2002 (Georgia Agricultural Statistics Service 2004).

Water use is a major issue in the poultry-processing industry. Federal sanitation regulations set up three years ago have caused poultry-processing plant consumption of water to increase significantly. These regulations require the meat industry to ensure products are as pathogen-free as possible, and poultry processors have used more water in processing to help solve this problem. Water-use restrictions during periods of drought can lead to increased competition between industrial and household users of water. Recycling not only reduces water use but also reduces volumes of wastewater. Therefore, finding an effective and efficient (physically and economically) way to deal with this issue could significantly benefit this industry.

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Objective

This research is to evaluate economically the recycling process of chiller water in a pilot poultry-processing plant using a polymeric ultrafiltration membrane system. The filtration system to be evaluated is provided by Sepro-Rochem Inc. (http://www.sepromembranes.com/tech.html)

Data Source

The Department of Food Science & Technology of The University of Georgia collects the experimental data for this work and is in charge of the physical evaluation of the filtration system. We also have used information from different suppliers of inputs.

Industrial Process And Water Consumption

The poultry industry in U.S. generally produces "ready-to-cook" poultry products. The universal industrial process can be summarized as Receiving → Killing → Bleeding → Defeathering → Eviscerating → Chilling → Weighing, Grading and Packaging → Shipping (USEPA 2002)

Carcasses should be chilled rapidly to below 40°F to minimize microbial growth and to preserve product quality (Tsai, Higby, and Schade 1995). To do this, most poultry plants use two chilling tanks in series, a pre-chiller and a main chiller. Several studies cited by the U.S. Environmental Protection Agency (EPA), have shown that the volume of water used and wastewater generated by poultry processing can vary substantially among processing plants. Per current USDA regulations, 0.5 gallon of water per bird must be overflowed from the chiller and replaced with fresh water.

Ultrafiltration Systems: Some General Specifications

Several different methods have been tested to evaluate their effectiveness on reconditioning broiler process water (waste-water treatments), such as direct ozonation with either slow-sand filtration, dissolved-air flotation, or diatomaceous-earth filtration. The Food Safety and Inspection Service of the USDA may allow reconditioning and recycling of chiller water. According to the Code of Federal Regulation (1987) cited by Chang and Toledo (1989), the basis for approving the use of recycling water includes:

- reconditioning equipment and conditions for use must be approved,
- reconditioning must achieve and maintain at least a 60% reduction in total microorganisms, and percentage reduction in coliform bacteria (*Escherichia coli* or *Salmonella spp.*) that may be present must be within 60 ±10,
- light transmission of the treated water must be at least 60% of that of the fresh water used in the process.

The same authors, using a filtration test unit of their construction, found that sometimes the total microbial reduction fell below 60%, suggesting possible use only when microbicides are added to the reconditioned water prior to recycling. They also found that the rate of filtrate flow dropped rapidly regardless of the use of filter aides, due to the deposition in the filter of two kinds of solids present in the overflow chiller water.

We can distinguish three main filtration categories, depending on the size of particles that are separated:

- Macrofiltration, conventionally defined as the filtration of particles that are 5-microns or larger;
- Microfiltration, which is a low-pressure cross-flow membrane process for separating colloidal and suspended particles in the range of 0.1-2 microns;
- Ultrafiltration is a selective-fractionation process using pressures up to 145 psi (10 bar). It concentrates suspended solids and solutes of molecular weight greater than 1,000. The permeate contains low-molecular-weight organic solutes and salts.

The main strength of membrane technology is that it works without the addition of chemicals, with a relatively low energy use, and is an easy, well-arranged conduction process.

Two factors determine the effectiveness of a membrane filtration process: selectivity and productivity. Selectivity is expressed as a parameter called retention or separation factor (expressed by the unit $l/m^2{\cdot}h$). Productivity is expressed as a parameter called flux (expressed by the unit $l/m^2{\cdot}h$). Selectivity and productivity are membrane-dependent (Lenntech 2004).

Results

Physical Data Collected by the Food Science and Technology Department

The Food Science and Technology team has conducted experiments with a smaller version of the membrane-technology system that they built in their labs. They also have modified the larger pilot system. Information obtained thus far shows the pilot plant processing 330,000 broilers daily, with a required volume of 165,000 gallons/day of fresh chiller water, recycling using two chillers for two 8-hour shifts, and 260 processing days/year.

The filtration units should be cleaned frequently: about 2 minutes every 8 hours with 10 liters (l) per unit of a solution containing 0.5% of cleaner, and about 2 minutes every 1 hour without cleaner, only using backflush with permeate. Information obtained with the small filtration unit (Singh et al. 2004) shows a total suspended solids (TSS) amount of 3.88 mg/l in the unfiltered water and an average of 1.42 mg/l after filtration (average of three samples). From this information we compute the percent average reduction in total suspended solids of the chiller water as:

$3.88 - 1.42 = 2.46 \rightarrow$ average reduction in TSS

$(2.46 / 3.88) \times 100 = 63.4\% \rightarrow$ percent average reduction in TSS

This data is consistent with previous research. Sheldon and Carawan (1989) cited a value of 65% for this TSS reduction.

Data from Other Sources

The average production of pollutants in U.S. poultry-processing plants, as well as an estimation of the annual example-unit's pollution, according to data gathered by EPA, Office of Water, is shown in Table 1. Kiepper (2003) found that the average chicken live-weight processed in the U.S. industry was 5.8 pounds. We can then estimate the total daily amount of pollutants produced at the pilot plant by multiplying the daily number of processed broilers by 5.8 and then by average pollutant produced per pound live weight killed (lb/LWK). That is, 5.8 x 330,000 = 1,914,000 lb/day LWK. Considering this broiler production and the average pollutant generation, we get an estimate of the average pollutants that our pilot firm is likely to produce (Table 1).

These data are especially important to compute possible savings if filtration reduces the amount of pollutant discharge. According to Sheldon and Carawan (1989), in some states there are sewage surcharge costs for industries, based on the level of biochemical oxygen demand (BOD) and TSS of the effluents. In Athens, Georgia, these surcharges reach $138 per 1,000 lb of BOD and $135 per 1,000 lb of TSS for the maximum allowed levels of pollutants (Department of Public Utilities, Athens Clarke County 2003), and are in addition to a wastewater charge by volume. Taking into account the average effluent concentrations of BOD and TSS in the poultry industry (EPA 2002), we used the above-mentioned ranges of surcharges. Sheldon and Carawan achieved average reductions of 65% in TSS and 61.8% in chemical oxygen demand (COD) using different filtration systems. They found a ratio BOD/COD = 69%.

Partial-Budget Analysis

With the available information thus far, the partial-budget method permits us an acceptable first approach to an economic evaluation of the recycling of chiller water.

The proposed change in the pilot plant's processing is the incorporation of a polymeric ultrafiltration-unit system, with the objective of recycling the chiller water by filtering its overflow. Each of these units comprises 150 m^2 of membrane. Considering a flow rate of 16.33 liters/hour per m^2 (average, considering membranes are fouled during the recycling operation, causing the original flux to drop), 16 units are required to filter the daily chiller overflow. Other budgetary information and assumptions are presented in Table 2.

Table 3 presents the partial-budgeting results in the pilot plant, accounting for the cost to discharge pollutants into surface waters. By recycling the chiller water, this plant could save $215,913.53 annually in water, sewage, and energy costs. Approximately 39% of this amount would come from water savings, 40% from sewage-cost savings, and 20% from energy savings (energy required to chill the water). These annual dollar savings exceed the additional costs of recycling, which amount to $105,834.51 annually. The main component of the additional costs is amortization of the filtration system (92%), followed by other items such as labor (especially for maintenance), cleaning costs, and miscellaneous. Thus the net annual change in income or gross margin after the proposed change is $110,079.01. The return rate per additional costs (net change/total annual debits) equals 104%, which, compared to the 35.5% profit before taxes/tangible

Table 1. Pollutant Generation in US Poultry Processing Plants and Pilot Unit.

	Pollutant Generation per Unit of Production in Broiler First-Processing Plants	Estimated Pollution of Pilot Unit
Parameter	Average[a]	Annual pollution[b] (lb)
BOD (lb/1,000 LWK)	0.14	68,873.38
COD (lb/1,000 LWK)	0.20	99,528.00
TSS (lb/1,000 LWK)	0.07	33,292.12

[a] United States Environmental Protection Agency (EPA), Office of Water, 2002
[b] Computed from [a] and taking into account annual Pilot Unit's production (330,000 birds per day x 5.8 lb/bird x 260 days).
BOD = Biochemical oxygen demand, COD = Chemical oxygen demand.
TSS = Total suspended solids, LWK = Live weight killed.

Table 2. Budget Information for Pilot Plant Chiller Water Recycling.

Factor		Price/cost/unit
SEPRO ROCHEM Ultrafiltration Polymeric Membrane Unit (excluding taxes, \$42,000/unit + \$20,000/10 membranes or 150 m^2)		\$62,000
Useful life of ultrafiltration unit		5 years, membranes 20 years, unit & pump
Filter cleaner [a] (Ultrasil 25)		\$ 1.886/liter
Cleaner use per unit		0.05 liters/8 hours
Labor wage[b]	\$ 9.29/hour	
Energy to chill the water[c]		12 watt-hr/bird
Energy cost of kilowatt-hour[d]	\$0.0429/kwh	
Efficiency of recycling chiller water with the filtration unit[e]		85%
Total daily chiller overflow[f]		624,525 liters
Sewage surcharge by level of pollutants [g]	and	\$138/1,000 lb of BOD \$135/1,000 lb of TSS
Sewage surcharge by volume [g]	+	\$1.54/100 cubic feet \$ 5.60 base charge
Labor, maintenance and cleaning (daily)[h]		\$ 9.27
Annual work-days of pilot plant		260 days

[a]Ecolab, Food and Beverage Division.
[b]U.S. Poultry & Egg Association and U.S. Department of Labor, 80% above the federal minimum wage.
[c]Graham, Strasser, and Mannapperuma (2002).
[d]*Advantage Georgia* (1998).
[e]Sheldon and Carawan (1989).
[f]165,000 gal, estimated from EPA requirement of 0.5 gallon per bird, multiplied by the 330,000 broilers/day that the pilot plant actually processes.
[g]Department of Public Utilities, Unified Government of Athens Clarke County, GA
[h]Assumed 1 hour/day for maintenance and cleaning; firm has two 8-hour shifts.

net worth and 12.4% profit before taxes/total assets of the upper quartile in this industry (RMA 2003), is decidedly superior.

Conclusions

Our initial findings in this approach to the economic feasibility of incorporating an ultrafiltration chiller-water recycling unit in the pilot poultry-processing plant indicate positive impacts on the profitability of this plant by more than \$100k per year. Importantly, this technology addresses the water-quantity and -quality issues that have been raised in this industry by reducing primary water used by approximately 36.5 m gallons and electrical energy use to chill water by nearly 1.03 gigawatt-hours annually in our pilot plant. Given that such poultry-processing plants can have very large local impacts, these averted water and sewage treatment savings are quite significant to municipalities and stressed watersheds.

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Table 3. Partial Budget for Incorporation of Ultrafiltration Units to Recycle Chiller Water in Pilot Plant, with Sewage Surcharge.

BUSINESS CREDITS		
ADDITIONAL ANNUAL RECEIPTS		
None	Total additional receipts	$ 0.00
B. REDUCED ANNUAL COSTS		
B.1 Energy savings by returning recycled chiller water 12 watts/bird		$ 44,169.84
B.2 Water savings (85% efficiency recycling chiller overflow)		$ 84,322.47
B.3 Sewage costs savings (in Athens Clarke, Georgia, 85% eff.)		$ 87,421.22
	Total reduced annual costs	$ 215,913.53
	Total annual credits	$ 215,913.53
BUSINESS DEBITS		
C. ANNUAL RECEIPTS REDUCTION		
None	Total reduced annual receipts	$ 0.00
D. ADDITIONAL DIRECT ANNUAL COSTS		
D.1 Depreciation (16 units, straight-line method, 20 & 5 years useful life, salvage value = 0)		$ 97,600.00
D.2 Labor ($9.27 /hour; 1 hour/ day)		$ 2,410.20
D.3 Filter - cleaning costs (0.1 L of cleaner/unit/day * 260 days* 16 units)		$ 784.58
D.4 Miscellaneous (5% of the additional direct annual costs)		$5,039.74
	Total additional annual costs	$105,834.51
	Total annual debits	$105,834.51
NET CHANGE IN INCOME (GROSS MARGIN)		$110,079.01

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