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Technical Memorandum

To: National Bioenergy Center

Title: Process Water Balance Diagrams for Corn Stover to Ethanol

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Abstract: The purpose of this memorandum is to enable the overall water balance for the Stover to Ethanol model to be more easily understood and visualized. With the use of several figures and tables, the process water demands and losses are tracked. The make-up water demands are then depicted as a series of 4 systems: Cooling Tower, Clean-in-place (CIP), Steam Cycle, and Process Demands. The flowrates correspond to values taken from the 2002 design report.

Keywords: Water balance; stover; ethanol; steam; CIP; cooling tower; makeup;

What follows is a series of progressive diagrams illustrating the overall balance. The first diagram (Figure 1) is a depiction of the specific process water inputs and losses. The stream numbers are listed, however the specific flowrates are not. The stream numbers are taken from the PFDs contained within the 2002 design report. Some may not exist within the simplified Aspen Plus model (e.g. 810. The proper stream to use in the simplified model would be 804C). Wastewater treatment (WWT) is included within this integrated process.

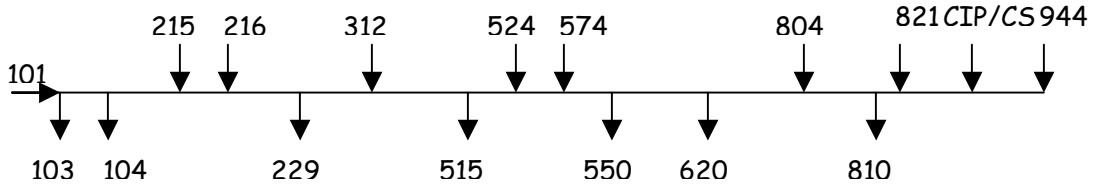

Figure 1. – Integrated Process Water Inputs and Outputs

The water enters the process either as a demand or as a happenstance input. The streams are listed and classified below.

Stream Number	Description	Demand? (Y/N)
101	Corn Stover Moisture	
215	Direct Injection Steam (LP)	Demand
216	Direct Injection Steam (HP)	Demand
312	Cellulase Enzyme	
524	Scrubber Water	Demand
574	Pretreatment Makeup (solids conc. adjustment)	Demand
804	Combustion Air	
821	Boiler Blowdown	
944	Cooling Tower Blowdown	

Table 1. – Process Water Inputs

As you can see, the overall process has 4 demand points for water: direction injection steam for pretreatment (high and low pressure), scrubber water, and water to adjust the moisture content of the process (pretreatment, saccharification, etc). The rest of the water entering the process comes "along for the ride" with other process streams. Corn stover has moisture, the cellulase enzyme is an aqueous broth, the combustion air has humidity, and the blowdown and CIP streams need to be treated and recovered.

As Figure 1 shows, water also leaves the system in several ways, as an evaporative emission, or leaving with a certain product stream (saleable or waste). These are listed and classified in Table 2 below.

Stream Number	Description	Product or Evap?
103	Spray Wash Evaporation	Evaporative
104	Solids from Stover Wash	Product
229	Gypsum	Product
515	Ethanol	Product
550	Scrubber Vent	Evaporative
620	Aerobic Lagoon Evap.	Evaporative
810	Flue Gas	Evaporative

Table 2. – Process Water Outputs

To satisfy all process water demands, additional makeup water is needed. This water source (assumed to be well water for now) enters as stream 903. In addition to the integrated process demands shown above, the water is actually used for 4 different systems: 1) Cooling tower system, 2) Clean-in-place system, 3) Steam system (cycle), and 4) the integrated process. This is depicted below in Figure 2, with the 4 systems color-coded and overlaid across the initial integrated process. Each cycle will be briefly discussed.

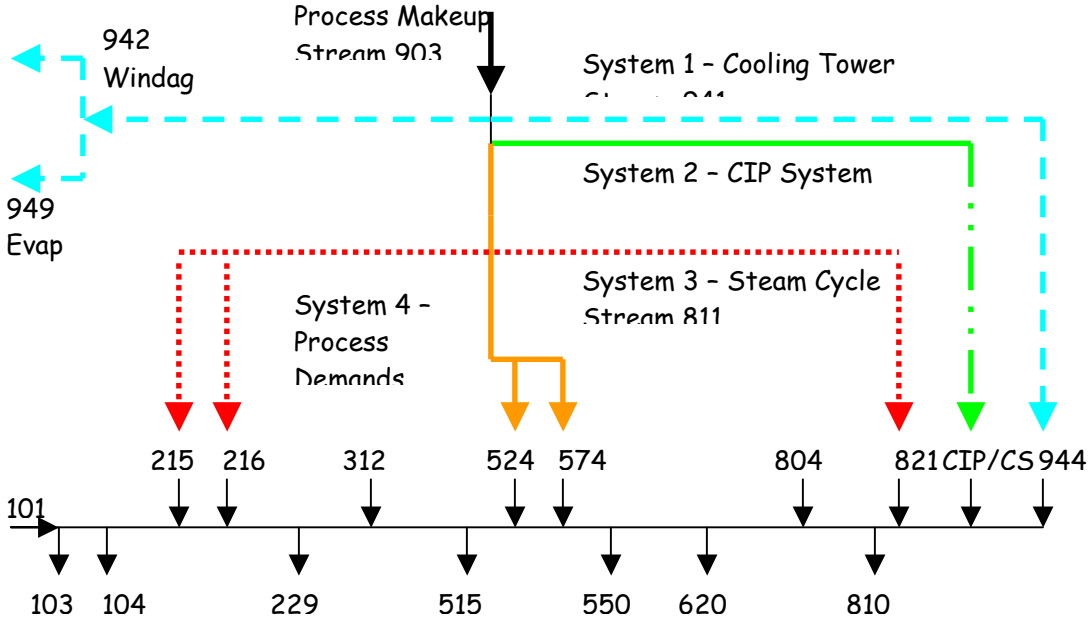

Figure 2. – Four Separate Water Systems

System 1 – Cooling Tower **(Blue)**: The cooling tower system is needed to cool certain process streams and/or maintain constant temperatures (e.g. fermentation, evaporator condensate, hydrolysate slurry). Fresh water (stream 941) is needed for the cooling tower as makeup for windage, evaporation, and blowdown losses. The blowdown (stream 944) is recaptured and enters the integrated process via wastewater treatment.

System 2 – CIP System **(Green)**: Fresh water is needed to clean some equipment such as the fermentors and evaporators that can have deposits buildup. The water is mixed with sterilization and cleaning chemicals to create the solution. The used CIP solution is then sent to wastewater treatment (WWT) for disposal. By doing so, it also enters the integrated process water cycle. Within the simplified model, the CIP/CS flowrate entering wastewater treatment is not included. The flowrate is very low and would contribute very little to the overall WWT demand. Instead, stream 906 is used only to back calculate the total fresh water (stream 903) required for the entire process. This is done within the Fortran block WATERDEM and is set at a constant estimated flowrate.

System 3 – Steam Cycle **(Red)**: The Steam cycle is used to generate high and low pressure steam for various process demands, including pressurizing the pretreatment reactors and driving distillation reboilers. Fresh water is needed to makeup for losses incurred when steam is injected directly into the integrated process, as well as for blowdown losses. Blowdown (stream 821) is recovered and sent to WWT, where it is treated and subsequently enters the integrated process as well. There are other potenial applications of this blowdown water, such as wetting the burner ash prior to waste disposal, or for spray-washing the initial stover feedstock.

The heat from the low pressure steam is used for heat exchangers and reboilers. If existing physically, the steam condenses, and the resulting condensate is collected, softened and deaerated, and recycled back to the beginning of the steam cycle. The system losses described above are made up with fresh water (stream 811). In the simplified Aspen Plus model, the low pressure steam is used for heat. As a result, these streams are not shown as material streams (they are, however, in the detail process model). Instead, the heat and energy flows are tracked. The FORTRAN block BOILECON is used to calculate all relevant parameters needed for the burner/boiler economics.

System 4 – Integrated Process Demands **(Orange):** Fresh water is required in the integrated process for scrubbing and for solids concentration adjustment. Fresh water (stream 524) flowing counter-currently to fermentation offgas helps to recover ethanol vapor from the CO_2 prior to venting it into the atmosphere. Doing this recovers more of the primary product, and also lowers the VOC emissions from the facility.

The fresh water (stream 574) is needed by pretreatment (and saccharification / fermentation) to adjust the solids concentration to the proper level. Recycled streams 573 and 516 are used for this purpose but do not have large enough flowrates to sufficiently lower the solids concentration to an operational level (30% total solids loading to pretreatment). Thus, fresh water (stream 574) is used to makeup the difference.

Conclusion

By examining Figure 2, the overall process water balance can be summarized. Instead of showing it here, it is listed in the 2002 design report, Table 20, page 53.