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CROMPION LLT CLARIFIER TECHNICAL DOCUMENT

INTRODUCTION

Crompion International is a Louisiana-based, globally operational world leader in providing specialty, low-nickel stainless steels and consulting services to a broad range of industries. As the world's leading manufacturer and distributor of Cromgard, high-performance stainless steel products, we pride ourselves not only on selling this specialty product, but on understanding how our customers use our products. In addition, through patented technologies developed with strategic partners, we have established ourselves as an innovative force that is helping to dramatically evolve the industries that we serve.

One of these technologies is the Crompion Louisiana Low Turbulence (LLT) Clarifier, which has been developed by a partnership between the Louisiana State University Agricultural Center and specialists from the sugar industry. The Crompion LLT Clarifier is a great innovation for the clarification of cane juice. The main advantage of this clarifier is that it utilizes turbulence reduction devices that eliminate the turbulent eddies in the flow, enhancing the clarification operation. Additionally, the clarifier incorporates a flash trough in the body of the clarifier that degasses the juice, providing more degassing area compared to an external flash tank of equivalent capacity while reducing the possibility of air entrainment. As a consequence, the Crompion LLT Clarifier provides shorter retention time, reduces sucrose losses and provides juice of high quality compared to other clarifier available in the industry. Finally, the Crompion LLT Clarifier is built with Cromgard Specialty Stainless Steel, which reduces maintenance needs.

CROMPION LLT CLARIFIER DESIGN CONCEPTS

The following basic considerations laid the groundwork for the design of the new Crompion LLT Clarifier.

- The endpoints of the distribution piping are fitted with simple turbulence reduction devices to cancel the momentum of the liquid jet, hence reduce the scale of turbulent eddies. This effect can be observed in figure 1.
- The feed channels are designed to maintain a relatively high flow to reduce the potential of plugging/scaling.
- A network of juice feed pipes introduces juice through a series of hydraulically uniform pathways over the cross sectional area of the clarifier. The basic scheme can be observed in figure 2.
- Juice overflow is collected through a series of uniformly distributed outlets at the top portion of the clarifier. This feature maintains uniform vertical juice velocity profiles to make full use of the cross-sectional area of the clarifier.

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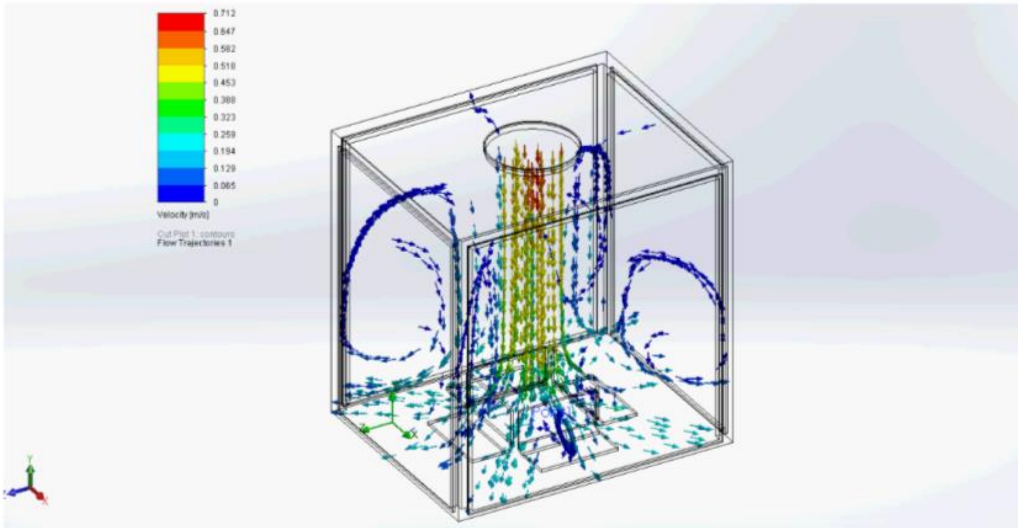

Figure 1: CFD Simulation of the Operation of the Turbulence Reduction Device.

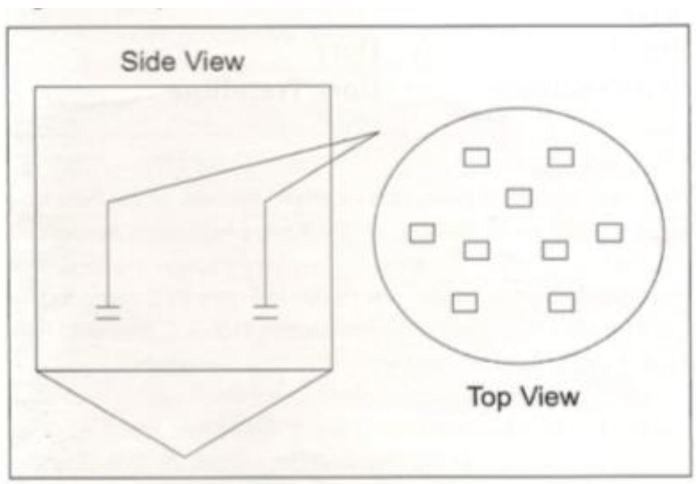

Figure 2: Layout of the TRD inside the Clarifier.

- The Crompion LLT Clarifier Next Generation comes with a built-in Flash Trough that degasses the juice without the need of an external flash tank. This design provides more degassing area compared to an external flash tank of equivalent capacity while reducing the factory footprint. Additionally, the Flash Trough avoids the necessity of additional piping and flash tank misplacements that lead to poor degassing and clarification problems.

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A top and side view of the Crompion LLT Clarifier can be observed in figure 3.

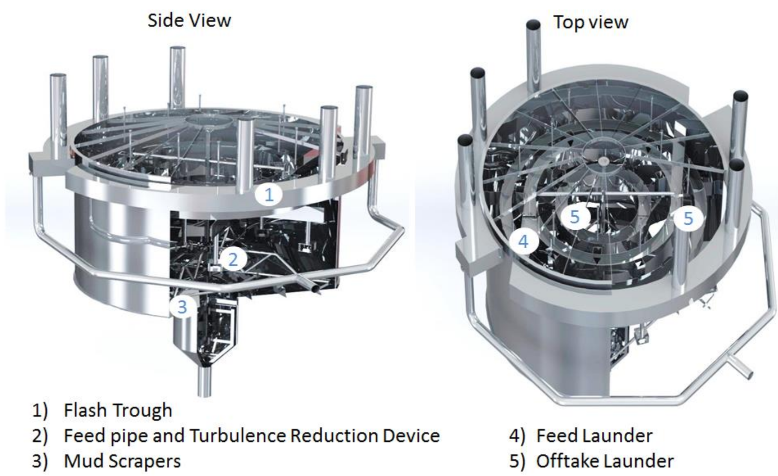

Figure 3: The Crompion LLT Clarifier.

PERFORMANCE OF THE LLT CLARIFIER

The performance of the Crompion LLT Clarifier has been compared to other clarifiers under Louisiana conditions, which are characterized by high mud content in cane that can be as high as 15%. The typical residence time achieved in a Crompion LLT Clarifier ranges between 25-30 minutes, compared to the Graver and Dorr type clarifiers, which have between 350-400% more retention time than the Crompion LLT Clarifier. Additionally, compared to a SRT type clarifier that can range between 30 to 60 minutes, the Crompion LLT clarifier has between 50 to 100% less retention time.

Moreover, the longer the retention time in the clarifier, the higher the inversion of sucrose. An estimation of the sugar inversion generated in each of the previously discussed clarifiers is shown in Table 1. Compared to the SRT, the Crompion LLT Clarifier can save approximately $43,282 per every million tons of cane grounded, this value triples when the Crompion LLT is compared to the Graver Type clarifier, saving up to $129,847 per every million tons of cane.

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Table 1: Inversion Estimations in Different Types of Clarifiers.

	LLT	SRT Type	Graver Type
Price of Sugar (¢/lb.)		21	
Residence Time (min)	30	60	120
Sugar Inverted (g/100 g Sucrose)	0.04	0.09	0.18
Juice Purity (%)	85	85	85
Total Sucrose Lost (metric ton/million TC)	93.5	187	373.9
Total Losses ($/Million TC)	43,281	86,563	173,127
Total Gain ($/Million TC)	-	43,282	129,847

PERFORMANCE STUDIES OF THE CROMPION LLT CLARIER

The first industrial implementation of the LLT clarifier was in 2010 at Sterling Sugars in Franklin, LA. During this season, two Clarifiers were run in parallel: an SRT clarifier with a diameter of approximately 12 meter and an average residence time of 74 minutes and a Crompion LLT clarifier with a 6.1 m diameter and an average residence time of 25 minutes. The average grinding rate for this factory was 12000 TCD.

Figure 4 shows the follow-up of the flow rate for each clarifier and the estimated retention time. It can be observed that the SRT has twice the retention time compared to the Crompion LLT Clarifier, which leads to higher sucrose losses. Additionally, when the performance of the clarifiers were compared in terms of turbidity, it can be observed that the Crompion LLT Clarifier had on average 23% lower turbidity than the SRT clarifier as shown in figure 5. In other words, the Crompion LLT Clarifier can handle high throughputs and manage the process variations without sacrificing the quality of the clear juice (Gaudet & Kochergin, 2013; Kochergin, Gaudet, & Robert, 2011). A similar behavior was observed during the 2013-2014 harvest season where the turbidity of the clear juice was measured at 900 nm using the ICUMSA method, the turbidity profile can be observed in figure 6.

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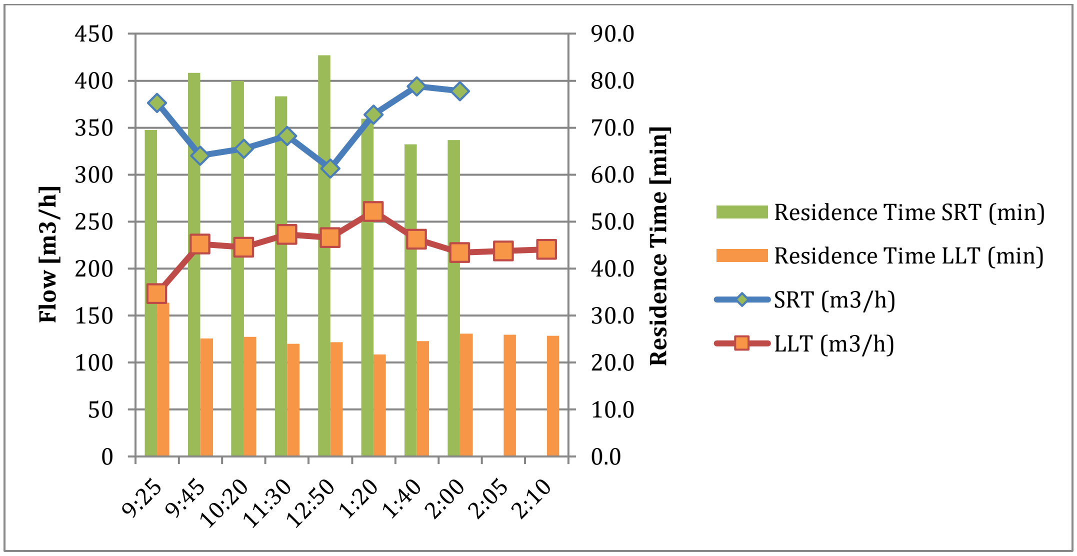

Figure 4: Flow rate and residence time during the 2010-2011 Harvest Season in Louisiana.

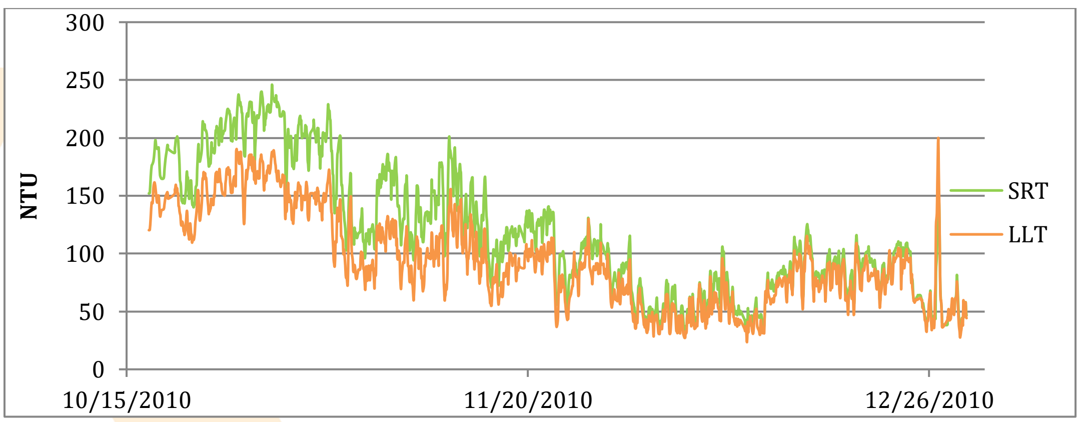

Figure 5: Turbidity Profile of the Clear Juice during the 2010-2011 Harvest Season in Louisiana.

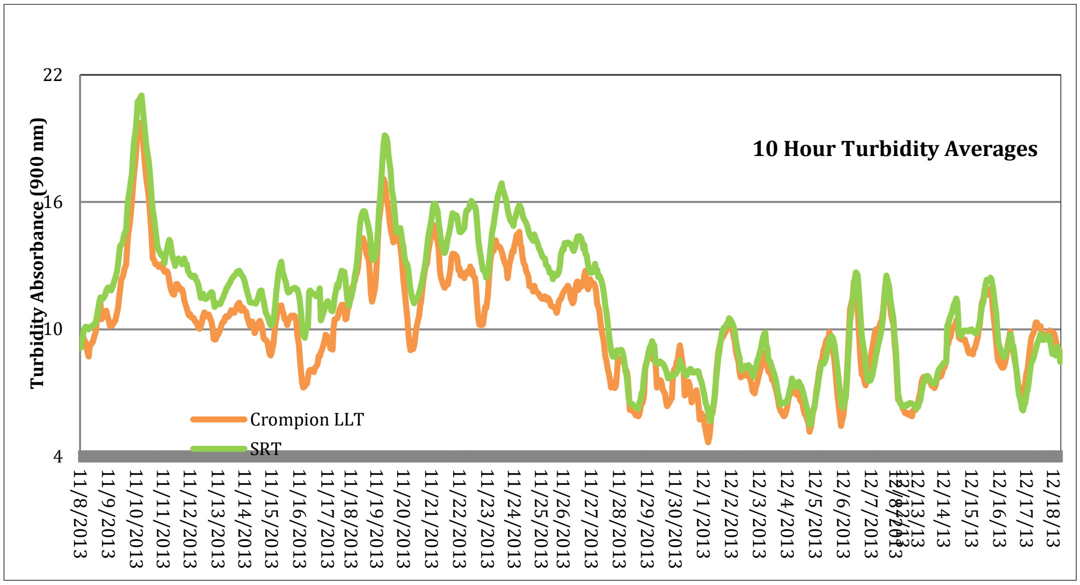

Figure 6: Turbidity Profile of the Clear Juice during the 2013-2014 Harvest Season in Louisiana.

Moreover, the Crompion LLT Clarifier has also been implemented at Andhra Sugars in India. A follow-up of the turbidity and color removal in a Crompion LLT Clarifier and a Graver type clarifier suggested that the Crompion LLT Clarifier removed approximately 90.42% of the turbidity and 33.34% of the color in approximately 37 minutes retention time. In comparison, the Graver type clarifier obtained comparable results but with a significantly higher retention time of 137 minutes (Narendranath & Lionnet, 2011).

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Table 2: Performance of the LLT Clarifier vs. a Graver Type Clarifier in Andhra Sugars, India.

	Turbidity Reduction (%)		Color Reduction (%)	
Date	Graver	LLT	Graver	LLT
6/2/2011	90.37	89.71	35.46	33.5
7/2/2011	91.12	89.34	33.5	36.31
8/2/2011	90.9	89.32	37.87	35.42
9/2/2011	89.04	89.54	36.31	32.32
10/2/2011	90.11	90.64	34.14	26.65
11/2/2011	90.42	90.42	35.42	32.59
12/2/2011	90.13	90.83	34.01	33.59
13/02/11	90.94	89.87	32.32	35.61
141/02/11	90.75	91.23	26.19	34.09
Average	90.42	90.10	33.91	33.34

Furthermore, during the performance assessment of the Crompion LLT Clarifier in India, it was observed that the temperature of the clear juice leaving the clarifier was 3 ^{0}C higher than the Graver type clarifier (Narendranath & Lionnet, 2011). An estimation of the energy and money savings this behavior brought showed that the sugar factory saved approximately 3000 metric tons of bagasse per every million metric tons of cane grounded, **with an estimated saving of approximately $78,000[1] per million metric tons of cane**. This is especially attractive for cogeneration factories or where the bagasse is used for applications other than fuel to the boilers.

[1] Assumptions: One metric ton of bagasse generates 1 metric ton of steam, the calorific capacity of bagasse was approximately 9740 kJ/kg, and the calorific capacity of Coal was 25000 kJ/kg. The price of coal and bagasse used was: $68.50 and $26 per ton, respectively.

THE CROMPION LLT FILTRATE CLARIFIER

Another application of the LLT Clarifier is Filtrate Clarification. Filtrate Clarification has many benefits: reduction of sucrose inversion by avoiding recirculation, which is detrimental to the process; increase in clarification capacity of the main clarifier by 15 to 20%; and reduction of invert sugars, which can lead to additional color generation in the factory. Since its first industrial implementation, the Crompion LLT Filtrate Clarifier has shown a very good performance; it has obtained a clear filtrate of comparable quality to the clear juice from the main clarifiers in a very short retention time, as low as 10 minutes (Grimaldo, 2013).

A follow-up of the filtrate clarifier constructed in Alma Plantation mill with approximately 10 minutes retention time showed the following results:

- An average turbidity of 250 NTU, which was lower than several batch settling tests performed in parallel to the filtrate clarifier operation.
- An average turbidity of 165 NTU units when the clear filtrate was combined with the main clarifier's clear juice, which is considered to have a good quality (<180 NTU) in Louisiana.
- Color removal of 17% with a 5730 IU average color of clear filtrate, which was below the expected color of the clear juice from the main clarifiers.
- A total removal of suspended solids greater than 87% with an average suspended solid concentration of 900 ppm.

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A summary of these results is shown in table 3.

Table 3: Performance of the Crompion Filtrate Clarifier during the 2012-2013 Harvest Season.

Parameter	Target	Mean Value Obtained During the operation
Turbidity Clear Filtrate (NTU)	<260	250
Turbidity of the Mixture Clear Filtrate and Clear Juice (NTU)	<180	165
Clear Filtrate Color (IU)	5936-7764	5730
Color Removal achieved in the VSRT (%)	15-32	17
Suspended Solids Removal achieved in the VSRT	69-93%	>87%
Clear Juice Residence Time [min]	-	<10

Finally, it has been estimated that by avoiding the recirculation of filtrate by implementing filtrate clarification in cane sugar factories and incremental recovery of 0.02% can be achieved (Prasad & Kafukp, 2005). This represents a revenue of approximately $92,000 per million tons of cane grounded[2] just by avoiding this recirculation that is highly detrimental to the process.

[2] This value has been estimated based on an average price of sugar of 21 cents per pound.

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ENERGY REQUIREMENTS FOR THE IMPLEMENTATION OF THE CROMPION LLT FILTRATE CLARIFIER

Filtrate clarification is a good alternative to improve the sugar quality, reduce sugar loss and enhance the clarification process. However, for many sugar mills increasing the steam requirements is a key parameter when choosing to implement or not a new technology. Therefore, the energy requirements of implementing a filtrate clarification process in a sugar mill have been estimated.

The simulation consisted in the assessment of three scenarios where the amount of exhaust steam required by the boiling house was calculated for each of them. The three scenarios simulated were: a sugar mill without filtrate clarification and the other two when filtrate clarification is implemented but using different types of steam for the heating requirements: exhaust and vapor I, respectively. It is important to mention that in the three scenarios parameters like the grinding rate, evaporation and boiling scheme, juice properties, etc. remained constant for the three simulations. Each scenario is explained in more detail below:

- First Scenario: The filtrate is recirculated back to the mixed juice tank.
- Second Scenario: Filtrate juice is heated from 70 to 105 ^{0}C (158-221 ^{0}F) before being clarified using exhaust steam from the power generation plant.
- Third Scenario: Filtrate Juice is heated from 70 to 105 ^{0}C (158-221 ^{0}F) before being clarified using vapor I (V1) coming from the first effect evaporators.

As stated previously, besides the implementation filtrate clarification, the general configuration of the factory remained unchanged. These characteristics, as well as other model assumptions are shown below:

Heat Radiation Losses:

- 5% radiation losses in live steam lines.
- 5% radiation losses in exhaust steam lines from the turbo-generators to the boiling house.
- 10% radiation losses in evaporators.

Steam Generation Plant:

- 3 boilers with a capacity of 99208 pounds of steam per hour (45 tons/h) and live steam of 250 psig and 390 ^{0}C (734 ^{0}F).
- Temperature of boilers feed water: 127 ^{0}C (261 ^{0}F).
- The boiler deaerator required exhaust steam for its operation.
- The steam generation plant included steam reducer valves (250 to 150 and 150 to 25 psig) to meet the exhaust steam requirements in case it was not enough.

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Power Generation Plant:

- 3 turbo-generators with 4 Mega-watt (MW) capacity each.
- Assumed mechanical and electrical efficiency: 0.97 and 0.92, respectively.
- Sugar mill electrical demand: 8.3 MW
- Exhaust Steam: 25 psig and 180 ^{0}C (356 ^{0}F)

Milling Tandem Plant

- Grinding rate: 10,000 tons per day.
- All milling tandem with electrical motors.
- Juice Extraction: 95%
- Cane Fiber: 14%
- Bagasse Moisture: 50%
- Bagasse Fiber: 48%

Boiling House

- The mixed juice was heated in two stages: the primary and secondary heaters utilized vapor II (V2) and vapor I (V1), respectively.
- The clear juice temperature was assumed to be 93^{0}C (199^{0}F). No clear juice heater was added to the model.
- Filter Cake: 5% Cane
- Filtrate Juice: 15% Cane
- Refractometric Dry Solids (RDS) of the Syrup: 65% Brix
- Vacuum pans steam requirements: 18% Cane
- Evaporation Scheme: A five effect evaporator scheme was simulated. The first effect supplies steam to the vacuum pans and secondary heaters. The second effect evaporator supplies steam to the primary heaters.

The three different scenarios are schematized in figures 7 and 8. Additionally, the power plant and evaporation schemes are shown in figures 9 and 10, respectively.

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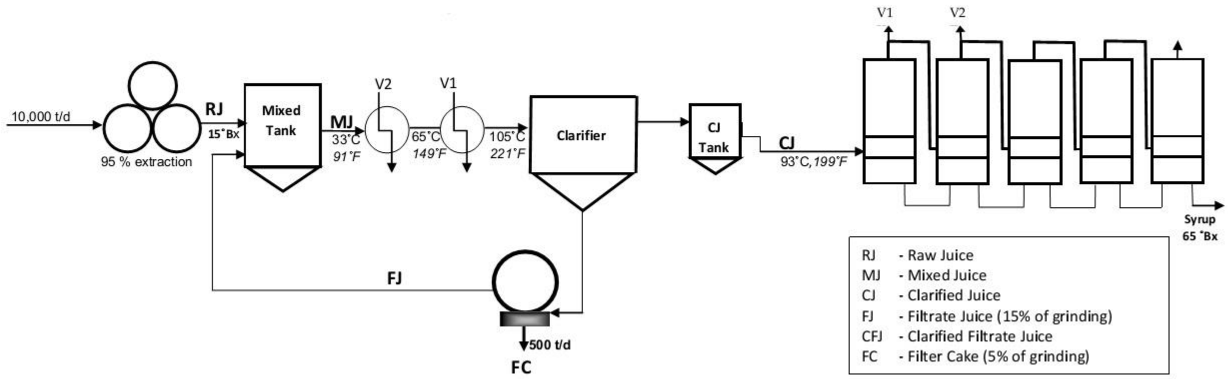

Figure 7: Sugar Factory without Filtrate Clarification.

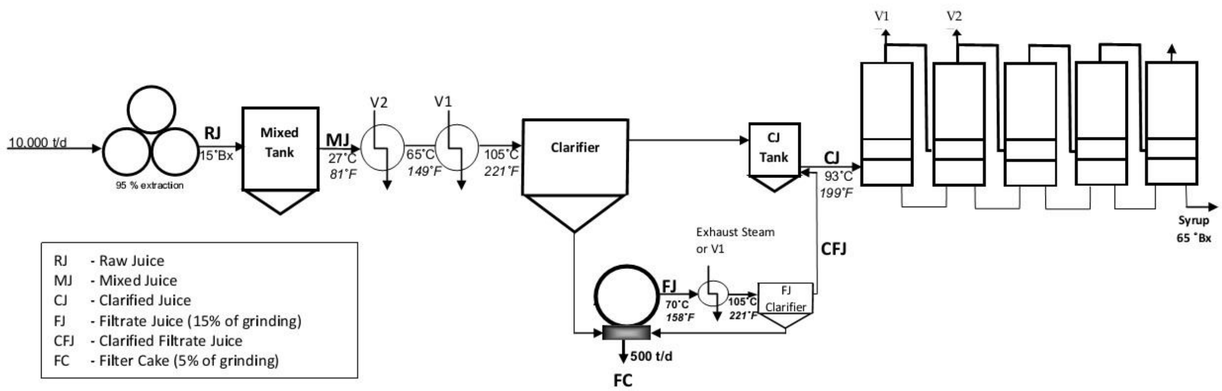

Figure 8: Sugar Factory with Filtrate Clarification.

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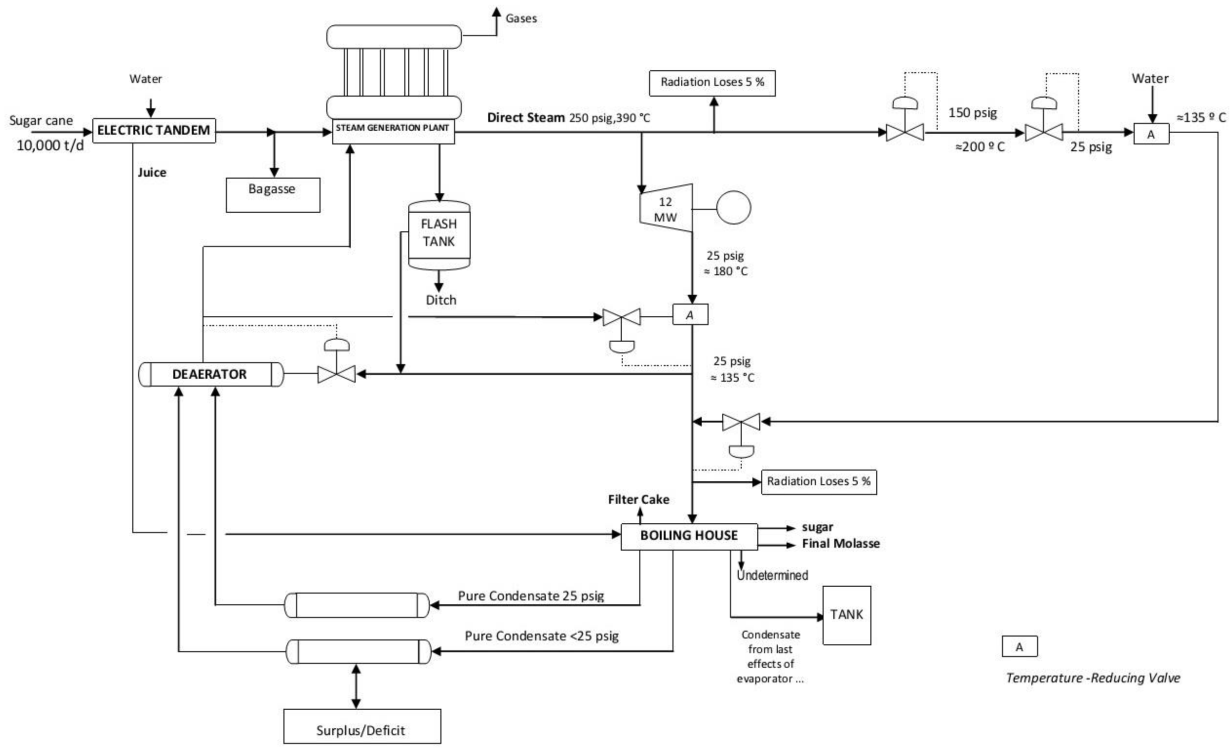

Figure 9: Power Plant Scheme.

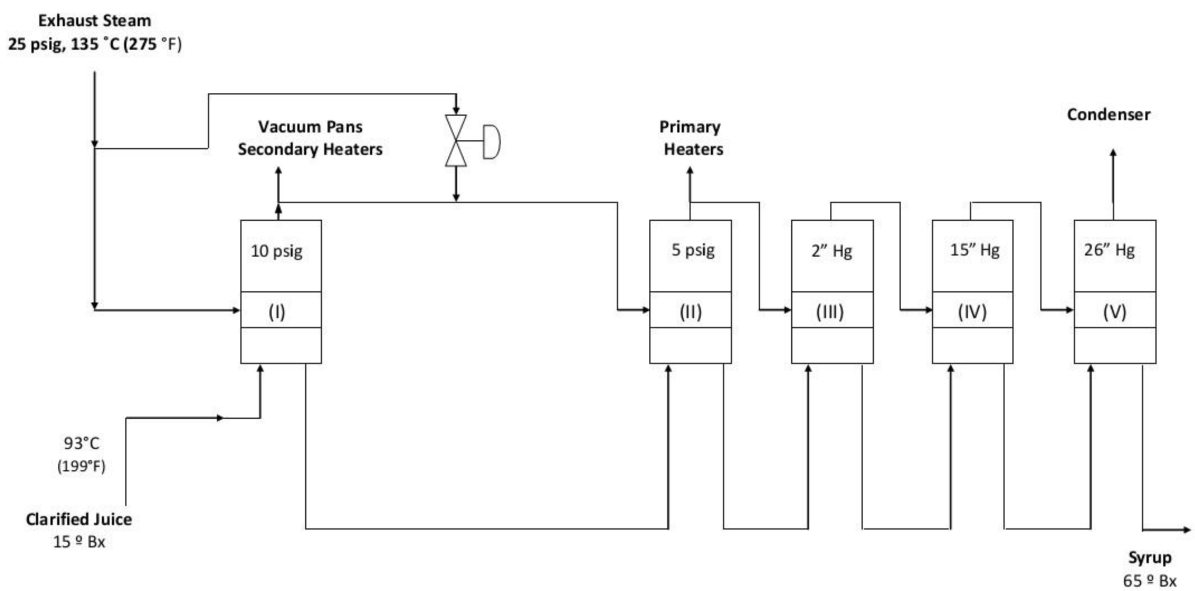

Figure 10: Evaporation Scheme.

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The results of the three simulations are summarized in table 4, where it can be observed that the exhaust steam consumption percent cane is not significantly different in the three scenarios. This means that the implementation of filtrate clarification would not impact negatively the steam economy of the factory or in other words, it is energy neutral.

Table 4: Steam Requirements of a Sugar Factory with and without Filtrate Clarification[3].

Process Area	Physical Properties	Scenarios		
		I	II	III
Milling Tandem				
Grinding rate		416,667	416,667	416,667
Bagasse		2704	2704	2704
Steam Generation Plant				
Live steam	250 psig 390 °C, 734°F	148,608	149,170	148,569
Live steam lost by radiation (5%)	251 psig 390 °C, 734°F	7,430	7,459	7,428
Live steam to power generation plant	252 psig 390 °C, 734°F	120,177	120,177	120,177
Live steam to steam pressure reducer valve	253 psig 390 °C, 734°F	21,002	21,535	20,964
Water to steam pressure reducer valve	127 °C, 261 °F	895	918	894
Power Generation Plant				
Exhaust steam from turbo generators	25 psig 180 °C, 356 °F	142,074	142,631	142,631
Water to steam temperature reducer valve	127 °C, 261 °F	6,057	6,081	6,056
Exhaust steam	25 psig 135 °C, 275 °F	148,131	148,712	148,089
Exhaust steam to deaerator	25 psig 135 °C, 275 °F	1,145	1,152	1,143
Exhaust steam lost by radiation (5%)	25 psig 135 °C, 275 °F	8,042	8,096	8,038
Exhaust steam from steam pressure reducer valves	25 psig 135 °C, 275 °F	21,897	22,453	21,858

[3] All the values in kilogram per hour unless stated differently.

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(Table 4 continued).

Exhaust steam to boiling house	25 psig 135 ^oC, 275 ^oF	**160,841**	**161,917**	**160,766**
Boiling House				
Steam to primary heaters	V2 (5 psig)	26,497	27,175	27,175
Steam to secondary heaters	V1 (10 psig)	33,400	28,845	28,845
Steam to filtrate juice heaters		0	Exhaust Steam 4,064	V1 3,985
Steam to vacuum pans	V1 (10 psig)	75,000	75,000	75,000
Exhaust steam to evaporators	25 psig 135 ^oC, 275 ^oF	160,841	157,852	160,766
Exhaust steam to boiling house	25 psig 135 ^oC, 275 ^oF	160,841	161,917	160,766
Raw Juice (15 ^{o}Brix)	27 ^oC, 81 ^oF	395,834	395,834	395,834
Mixed Juice		458,334	395,834	395,834
Filtrate Juice	70 ^oC, 158 ^oF	62,500	62,500	62,500
Clarified Juice	93 ^oC, 199 ^oF	375,000	375,000	375,000
Syrup (65 ^{o}Brix)		86,539	86,539	86,539
Exhaust steam consumption % Cane		**38.6%**	**38.9%**	**38.6%**

CONCLUSIONS

- Different studies show that the Crompion LLT Clarifier provides juice with low turbidity and color in a short retention time compared to other clarifiers, while reducing the sucrose losses.
- The Flash Trough® & TRD® incorporated in the Crompion LLT Clarifier enhances the performance of the clarifier because it provides more degassing area compared to an external flash tank and dissipating the turbulent eddies of the flow, respectively, which are essential to achieve a good clarification.
- The design of the Crompion LLT Clarifier is simple, making it easy to construct and maintain.
- An assessment of the Crompion LLT Clarifier showed that it could lead to energy savings by providing a clear juice with higher temperature compared to other clarifiers.
- The Crompion Filtrate Clarifier can reduce the sucrose losses and increase the main clarifiers capacity by avoiding the recirculation of filtrate that is detrimental to the

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process. This clarifier has a very short retention time, approximately 10 minutes, making it possible to process high throughputs of filtrate in a small unit.

- A simulation of a sugar factory with and without the implementation of filtrate clarification shows that the steam economy of the factory would not be affected by the implementation of this technology.

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