

**A REVIEW OF THE CAUSE AND EFFECT RELATIONSHIPS WITHIN
THE PROCESSES OF A SUGAR FACTORY**

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ABSTRACT

Processes within a sugar factory are relatively simple; however, it is the interaction between these processes that define the efficiency of the production of raw sugar. This document covers the processes from when the sugarcane enters the factory to the production of dried raw sugar. In depth analysis of the various processes is not undertaken, the cause and effects within and between the processes is the focus of the review. With the knowledge gained from analysing these interactions it should be possible to find problem areas within the factory that require further optimisation. The integration of these problem areas into the sugarcane supply chain is then possible thus allowing for a more comprehensive system analysis.

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1. INTRODUCTION

The production of raw sugar involves the extraction of sucrose from the sugarcane stalk and the subsequent crystallisation of the extracted sucrose. The aim of any sugar factory is to produce high quality raw sugar at minimum cost and complexity. Throughout the production of raw sugar steps are taken to minimise the impurities and colour of the final sugar crystals. The quality of the final sugar crystals is affected by factors both external and internal to the sugar factory.

The purpose of this literature review is to determine the cause and effect relationships present in the sugar factory. It should be noted that the literature review will focus on a macro-view of the factory as an integrated system. In depth analysis of each process will not be undertaken. From the information gathered it should be possible to create performance analysis tools which can be used in a number of sugar factories to determine the root causes of inefficient operation. Small but pertinent changes can then be made to the factory operations which will result in high quality sugar and lower operation costs.

The aims of this literature review are therefore to:

- Provide a brief outline of the processes within the sugar factory.
- Explain the various problems and root causes associated with each unit operation.
- Explain how these problems effect subsequent unit operations.

The processes within the sugar factory are fairly generic only differing in the equipment used. Peter Rein published a cane sugar engineering hand book in 2007 which comprehensively cover the production of sugar. This reference has been used throughout the literature review to introduce each process. The cause and effect relationships covered have been sourced from studies conducted mainly in South African sugar factories as well as around the world.

The first step in the production of raw sugar is the preparation of the cane stalk. This involves the washing of the cane, knifing and shredding to produce a cane fibre bed (Rein, 2007). The fibre bed is fed into either a diffuser or milling tandem. The aim of the diffuser or mill is to extract sucrose from the fibre bed with the least amount of impurities (Rein, 2007). The

diffuser uses hot water to wash the sucrose from the fibre bed, while the milling tandems use pressure as well as a relatively small amount of water to remove the sucrose (Rein, 2007).

The juice extracted from the diffuser or milling tandem, most commonly termed raw juice, is passed through a clarifier. The clarifier removes unwanted substances from the raw juice such as soil, cane fibre particles and impurities that contribute towards a darker raw sugar colour (Rein, 2007). The clarifier uses various flocculants which collect unwanted particles causing them to settle to the bottom of the tank forming a mud (Rein, 2007). The solution that results from the clarifier is termed clear juice. Mud is a waste product and is passed through a press filter where excessive water is removed and where the remaining solids are usually returned to the fields as fertiliser (Engelbrecht *et al.*, 2009). An alternative to filtering mud is to pass it back into the diffuser, here the cane fibre acts as a filter (Rein, 2007).

Evaporation follows the clarification process. In the evaporation process the water content of the clear juice is reduced in order to form syrup (Rein, 2007). The syrup is then processed through three evaporation/crystallisation pans, A, B and C, with each pan evaporating lower quality syrup (Rein, 2007). With the addition of seed crystals to these pans, crystallisation occurs growing the seed crystals (Rein, 2007). After evaporation in the pans the resultant sugar crystals and clear juice, now termed massecuite, is mixed to obtain an even consistency then passed through a centrifuge (Engelbrecht *et al.*, 2009). The centrifuge removes the sugar crystals from the remaining syrup. The crystals are then sent on to drying and storage/packaging. The remaining syrup is passed to the next evaporation pan or passed out of the C pan as molasses (Engelbrecht *et al.*, 2009). The newly created sugar crystals are dried to ensure suitable properties for handling and to prevent degradation during storage (Rein, 2007).

The processes outlined above are shown in a flow diagram Figure 1.1. To the right of each process are the performance metrics for that process. So as to not clutter the diagram the only input and output to the system is sugarcane and dry raw sugar. Major outputs that have not been included are bagasse, filter cake, molasses and water.

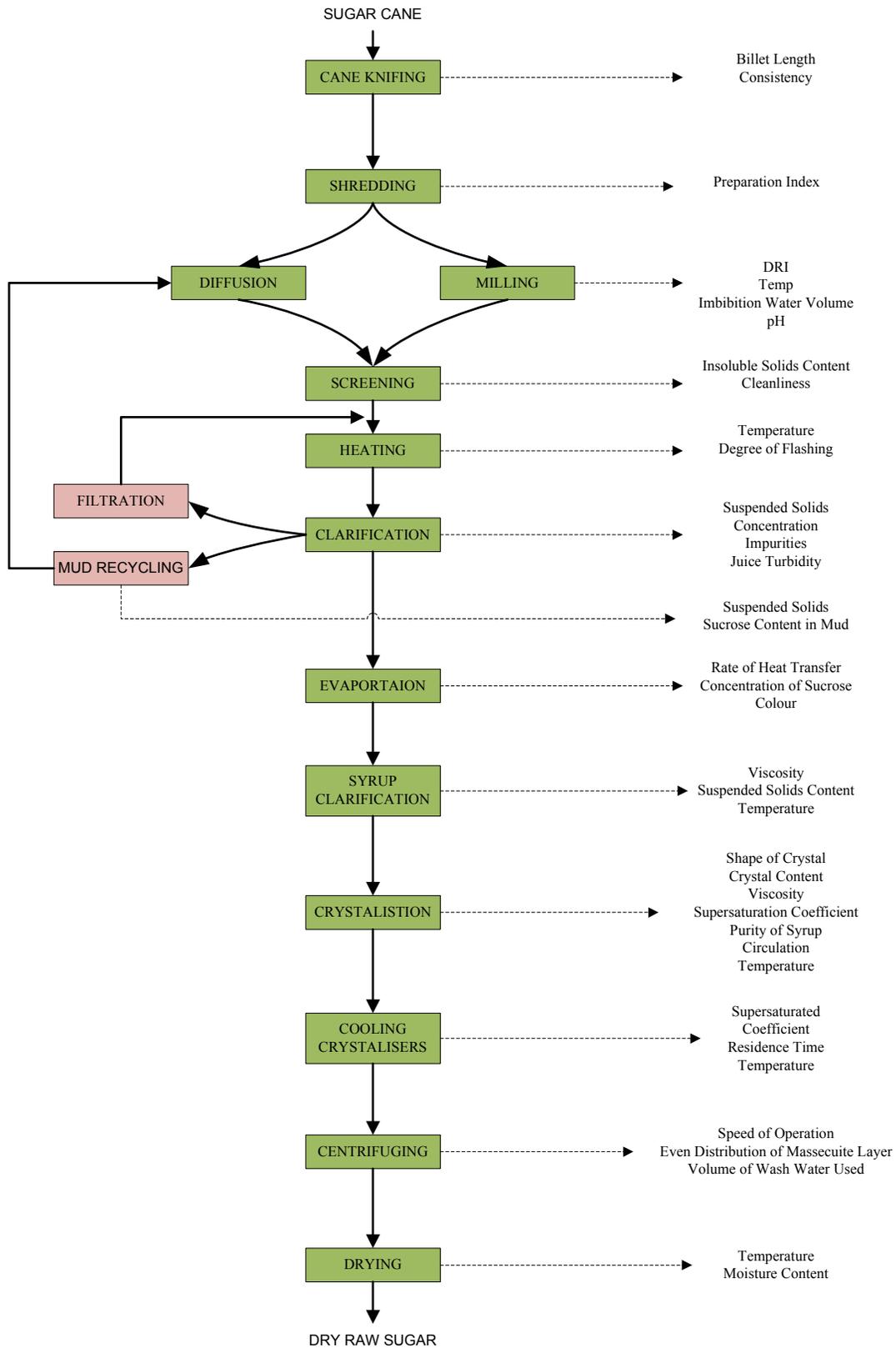


Figure 1.1 Generic steps of raw sugar production, after (Engelbrecht *et al.*, 2009).

2. CAUSE AND EFFECTS WITHIN THE SUGAR FACTORY

The quality of raw sugar that the sugar factory can produce is limited by the quality of the sugarcane that is delivered to the factory. There are however steps within the factory that can help to mitigate poor sugarcane quality. A brief outline of the process is given after which the various problems and root causes associated with each unit operation are considered.

2.1 Input and Output Characteristics of the Sugar Factory

Sugar factories have to deal with a wide variation in the quality of raw material. Variability in the sugarcane is as a result of the high number of role players in the upstream supply chain as well as climatic variation.

2.1.1 Input Factors

There are a number of factors that affect the processes throughout the mill. The most important of these factors is cane quality. Without high quality cane, quality sugar cannot be produced.

The quality of the cane is affected by the delay between harvesting and crushing (Barnes *et al.*, 1998), the method of harvesting (Meyer *et al.*, 2002), cane variety (Barker and Davis, 2005) and the time of year that the cane is harvested hence the prevailing climatic conditions (Barker and Davis, 2005; Smits and Blunt, 1976). For example, an increase in the delay of transferring the harvested cane to the mill increases the loss of sucrose as well as the buildup of impurities in the cane stalk (Reid and Lionnet, 1989; Ravno and Purchase, 2005). The prevailing climatic conditions exacerbate the losses and build up of impurities (Reid and Lionnet, 1989). During the warm wet summer months, deterioration rates are higher compared to winter months (Ravno and Purchase, 2005). The purity of the sugarcane crop changes as the season progresses (Lonsdale and Gosnell, 1976). Lonsdale and Grosnell (1976), found that that purity is lowest in the beginning of the season, *i.e.* March, and increases in July after which it is fairly constant until December. Eggleston and Harper (2006)

found that mannitol, formed by the bacterial degradation of sugarcane, is a good indicator of cane quality.

Dextran is formed from the breakdown of sucrose as a result of bacterial action, thus important factors that control its formation are temperature, moisture and residence time (Ravno and Purchase, 2005). The formation of dextran is also increased when mechanical chopper harvesting is undertaken due the increased surface area and exposure of the cane ends to contamination (Ravno and Purchase, 2005).

If the cane has not been completely burnt it has been reported that the dextran content increases (Simpson and Davis, 1998). Dextran creates a number of problems throughout the sugar factory as well as within the subsequent refinery. The dextran also forms a sticky residue to which soil particles attach contributing to the soil entering the factory (Simpson and Davis, 1998). Simpson and Davis (1998) suggest that high cane soil content will cause excessively high levels of mud. This in turn causes insoluble calcium phosphate, a suspended solid, to be carried over into the clear juice resulting in poor quality sugar (Simpson and Davis, 1998).

2.1.2 Output Requirements

Raw sugar can be consumed directly however it is usually processed further in a sugar refinery. The sugar factory is therefore required to produce a raw sugar that meets the expectations of the refiner. Sugar quality is measured according to a variety of factors namely, pol, colour, ash, insoluble solids, filterability, dextran, starch, reducing sugars and grain size/distribution (Rein, 2007). All of the above affect the cost and ease of refining.

In South African raw sugars are divided into three quality groups (Rein, 2007). The groups are classified according to the parameters mentioned above. Table 2.1 gives the values with which the raw sugar qualities are analysed. Payments for raw sugar are based on the pol value of the raw sugar in addition to this there are bonuses and penalties for the various characteristics of the sugar (Rein, 2007).

Table 2.1 Analysis for grades of sugar in South Africa (after Rein, 2007)

	Very High Pol	High Pol	Low Pol
	(VHP)	(HP)	(LP)
Pol in °Z	99.3	98.9	97.8
Moisture in g/100 g	0.1	0.24	0.35
Reducing Sugars in g/100 g	0.16	0.5	1.1
Ash in g/100 g	0.15	0.17	0.2
Colour in IU	1500	1800	2200
Starch in mg/kg	110	110	110
Dextran in mg/kg	90	90	90

2.2 Juice Extraction

Sugar is delivered to the factory as either complete stalks or billeted into shorter pieces (Engelbrecht *et al.*, 2009). The cane undergoes three processes before bagasse and raw juice are produced, namely cane knifing, shredding, and milling or diffusion (Engelbrecht *et al.*, 2009). The purpose of juice extraction is to rupture as many cane plant cells as possible then to separate the soluble particles from the insoluble (Payne, 1968; Moor, 1994).

2.2.1 Cane Knifing

If not already billeted, as a result of mechanical copper harvesting, cane knifing involves the reduction in size of the cane stalk into small billeted pieces (Rein, 2007). Cane knifing prepares the stalks into an even bed that will ensure a stable flow of cane into the shredder without blockages (Ried, 1994). Ried (1994) reports that the tip velocity of the knives affects the quality of the preparation. The knifing of the cane should not cause an excessive reduction in fibre length as this would impede diffusion (Reid, 1995). Longer fibre lengths ensure that the fibre bed in the diffuser is loosely packed, allowing for higher percolation rates (Reid, 1995). The concerns with the cane knives are wearing and damage due to excessive soil, rocks and foreign objects, such as metal chains in the incoming cane (Ried, 1994). There is an increase in the amount of soil entering the mill during rainy weather (Ried, 1994). Following knifing, the billeted cane is fed into the shredder which serves to rupture the cell walls of the cane stalk.

2.2.2 Shredding

Shredding is achieved by feeding the billeted cane from the knifing process through a series of hammers, which shred the billets into a fine bed of fibre (Moor, 1994). It involves the extensive destruction of the cell walls of the cane stalk (Reid, 1995). Complete destruction of the cell ensures a high extraction rate in the diffuser (Payne, 1968; Moor, 1994). In the report of cane shredding, Moor (1994) states that cane should not be over prepared as it leads to “pulping” of the fibre. Pulping causes difficulties in the transfer of fibre through the mill and leads to decreased percolation rates in the diffuser (Moor, 1994). The same applies for the shredder as did with the knifing machinery, *i.e.* wear and damaged results from soil, rocks and foreign objects, which leads to poor preparation and hence poor extraction in the diffuser (Smits and Blunt, 1976).

The shredding of the billeted cane stalk is measured using the Preparation Index (PI). This is amount of sucrose that can be washed from the cane relative to the total quality of sucrose present measured as a percentage (Loubser and Gooch, 2004). However, there is a new method to measure the preparation of cane, *viz.*, the Diffusion Rate Index (DRI). The DRI is a measure of the time taken to remove a certain Brix from the shredded cane sample (Loubser and Gooch, 2004). It is thus a measure of how easily Brix can be removed rather than how many cane cells are open as the PI method is (Loubser and Gooch, 2004). Brix is the measure of dissolved solids in sugar, juice, liquor or syrup using a refractometer in units of °Bx (Rein, 2007). For example, in the case of a pure sugar-water solution of 25°Bx there is 1 part sugar to 3 parts water.

2.2.3 Milling

Milling uses pressure to expel the fluids from the fibre bed (Engelbrecht *et al.*, 2009). The fibre bed is first mixed with water and then passed through a series of mills (Engelbrecht *et al.*, 2009). Milling is no longer a popular method of extraction in sugar factories, with only 9% of sugarcane in South Africa processed by milling (Lionnet *et al.*, 2005). This is as a result of the higher extraction achieved by the diffusers as well as a higher quality raw juice (Reid, 1995).

A problem experienced with milling tandems is the build up of slim from micro-organism fermentation of sugar juices (Reid, 1995). This is particularly evident when the cleanliness of the milling tandem is not maintained (Reid, 1995).

2.2.4 Diffusion

The diffuser is the more common method of extraction of sucrose from the cane fibre and has largely replaced milling (Reid, 1995). Soluble particles are washed out of the cane by a counter-current leaching process (Rein and Woodburn, 1974). The amount of soil, degree of cane preparation, bulk fibre density and pH of the percolating liquid has an effect on the diffuser efficiency (Lionnet *et al.*, 2005). These factors contribute to the rate at which percolation takes place.

Poor percolation results in flooding, hence a decrease in extraction (Lionnet *et al.*, 2005). Operational problems concerning flooding include overflow of fibre out the feed or discharge ends of the diffuser and spilling cane juice (Lionnet *et al.*, 2005). Mitigation of the problems results in downtime and hence a reduction in the volume of cane processed (Lionnet *et al.*, 2005). Flooding can be avoided by decreasing the throughput and imbibition of the diffuser, *i.e.* allowing more time for percolation (Rama *et al.*, 2006). Rama (2006) also suggests removing suspended solids from the cane bed to ensure efficient permeability especially during high ash loads.

High loads of suspended solids enter the mill with the cane as a result of high soil loads. This usually occurs during rainy weather, especially when there is a delay between harvest and milling, allowing the dextran “glue” to accumulate soil (Simpson and Davis, 1998). High clay content soil has the most effect on the percolation rate (Lionnet *et al.*, 2005). In experiments conducted by Lionnet (2005), and confirmed by Rama (2006), it was found that the impermeable nature of clay prevented the free flow of imbibition water through the samples.

Liming in the diffuser is undertaken to maintain high pH imbibition water in order to reduce the silica levels in the clear juice, limit corrosion and reduce inversion (Walthew *et al.*, 1998). Inversion is the changing of sucrose to glucose and fructose (Rein, 2007). Reducing silica levels helps prevent scale build up in the evaporators (Walthew *et al.*, 1998). Liming, however, may also reduce the permeability of the cane bed (Lionnet *et al.*, 2005). If poor

quality lime is used, *i.e.* lime containing extra silica, the positive effect of a high pH will not be realised (Lionnet and Walthew, 2004). At a high pH both silica and Brix will continue to be leached from the cane fibre, however, the rate at which Brix is leached will decrease more rapidly than that of silica (Walthew *et al.*, 1998). This is more significant if the pH of the solution is above 8.5 (Lionnet and Walthew, 2004). Silica is not easily removed during clarification (Walthew *et al.*, 1998).

Temperature affects the rate of sucrose extraction in the diffuser. Reid (1995) suggests that temperatures should be maintained above 75°C in order to attain high extraction rates. The average temperature of the diffuser should thus to be maintained at 85°C (Reid, 1995). High temperatures result in an increase in the juice colour (Reid, 1995). For example, Reid (1995) reports that at Amatikulu Mill a 10°C drop in temperature resulted in a 25% reduction in colour.

Diffusion results in raw sugar of higher colour, but lower impurities than that of milling (Reid, 1995). This is however dependent on the temperature of the diffuser (Reid, 1995). According to Reid (1995) on average raw sugar colour from a diffuser is about 25% higher than sugar from a milling tandem. This may be a disadvantage when the goal is to produce a low colour sugar or when milling a white sugar (Reid, 1995). The advantage of the diffuser, however, is the fact that the starch is removed from the raw juice as a result of the high temperatures (Reid, 1995). The higher temperature denatures the starch allowing enzymes to break the starch down further (Reid, 1995).

In diffusers the measurement of microbiological breakdown is possible. The organism hyperthermophiles is responsible for the breakdown of sucrose to lactic acid (Reid, 1995). The lactic acid content in the diffuser is measureable, therefore, there is a relationship that exists between the sucrose lost and the lactic acid produced (Reid, 1995). For every part of lactic acid formed there is a resultant two parts sucrose loss as well as a drop in juice purity (Reid, 1995). Cane fibre that is left in the diffuser is prone to mibrobiological breakdown. Therefore the start up and shut down times in a diffuser are a cause of concern in a sugar factory (Reid, 1995). If the stops last for over six hours it is advisable to clear the cane fibre in the diffuser to prevent the degradation of the sugar (Reid, 1995).

2.3 Energy Production and Consumption

Sugar factories have the potential to produce enough energy to operate without the input from external sources. There however are factors that change the amount and quality of fuel supplied to the boilers as well as the efficiency of the boilers.

2.3.1 Energy Supply

The energy in a sugar factory is supplied mainly by the burning of bagasse, the waste product of sucrose extraction. The bagasse is fed into the boilers where it is burned for steam and electrical energy production (Rein, 2007). Energy is required at all times within the factory even if the processing of cane has ceased (Ried, 2006). Thus, there is a requirement to store excess bagasse or to have an alternative source of energy, such as coal (Ried, 2006).

The quantity and quality of the bagasse affects the amount of energy that is available for steam production. The quantity of the bagasse is measured by the fibre content of the cane, while the quality is measured by the calorific value and combustion efficiency (Ried, 2006). The calorific value of bagasse is not significantly affected by the amount of fibre, pith, cane stalks and cane tops (Don and Mellet, 1977). Ried (2006) states that the most important factor concerning the calorific value and combustion efficiency of the bagasse is the amount of water remaining after sucrose extraction. The moisture of the bagasse is controlled at the dewatering mill, if the moisture content rises to above 55 % additional alternative fuel needs to be added, often in the form of coal (Ried, 2006). Alternative fuel may also need to be added if the ash percentage in the bagasse rises above 5% (Ried, 2006). The ash percentage is dependent on the weather and harvesting technique as mentioned in Section 2.1.

The majority of energy used within the sugar factory occurs during the evaporation of water from the cane juice (Ried, 2006). Increasing the amount of imbibition water used during diffusion and milling increases the amount of sucrose extracted (Rein, 2007). However increasing the imbibition water dilutes the raw juice thus requiring more energy to evaporate (Ried, 2006). A further addition of water occurs in the vacuum pan to maintain and control the growth of crystals and in the centrifuge to wash the crystals of syrup (Ried, 2006). Both these processes place a further demand on energy for evaporation (Ried, 2006). In the case of

poor syrup quality as a result of poor cane quality an increased in the amount of water may be required (Ried, 2006).

2.3.2 Boilers

The boiler converts the by product from sugar extraction, bagasse, to steam and electrical energy for use in the sugar factory. If the quantity of bagasse is insufficient the boiler energy supply can be supplemented using coal, fuel oil, natural gas and wood waste (Rein, 2007). The operation and maintenance of the boiler is affected by the quality of the incoming fuel, which in most cases is bagasse, and the quality of the boiler feed water. Sand in the bagasse, more typical of diffusers, can result in wear in the boilers (Reid, 1995).

The quality of the feed water to the boiler affects the operation and maintenance of the boiler (Reid and Dunsmore, 1991). Sucrose is identified as a great cause of boiler problems. Reid and Dunsmore (1991) report that if sucrose contamination occurs at a concentration more than 200 ppm operational problems within the boiler can be expected. At high temperatures the sucrose breaks down into organic acids. These lower the pH of the feed water causing an increase in conductivity resulting in corrosion (Reid and Dunsmore, 1991). To correct the low pH caustic soda can be added to the feed water to bring the pH back to the required 11.0. Dosing with caustic soda however is not desired and it can increase the total dissolved solids (Reid and Dunsmore, 1991).

Damage to the boiler components as a result of sucrose can result in costly repairs and boiler downtime. Some examples of damage and problems as listed by Reid and Dunsmore are foaming, carry-over and fouling of strainers, steam traps, control valves and turbine blades. Carbonaceous deposits can also form on the boiler drum and heating surfaces reducing heat transfer and may cause blockages or corrosion (Reid and Dunsmore, 1991). Sucrose concentrations of 20 ppm are deemed as being safe provided the chemical treatment of feed water is adequate (Reid and Dunsmore, 1991).

The chemical treatment of the water aids in the control of deposits and scaling of insoluble compounds in the boilers (Cuddihy *et al.*, 2005). The deposit and scaling are as a result of a decreasing solubility of the deposit forming salts with increasing temperature and

concentration (Cuddihy *et al.*, 2005). Cuddihy (2005) reports that there are six mechanisms by which deposits and scale can form in the boilers. These are summarised in the table below.

Table 2.2 Cause and effect of deposits and scale within the boiler

Cause	Result	Effect
Precipitation of compounds.	Formation of hard deposits on the heater transfer surfaces.	<ul style="list-style-type: none"> • Restrict water flow. • Cause feedwater regulating valves to malfunction. • Decrease heat transfer in stage heaters and economizers. • Contribute to under deposit localised corrosion which may result in tube rupture. • Reduce circulation through tubes. • Retard heat transfer. • Increasing temperatures results in softening of boiler tube metal which may result in rupture. • Energy wastage.
Improper selection or inadequate control of chemical sludge conditioners and dispersants.	Inadequate conditioning and dispersion to prevent adherence to boiler metal.	
Supersaturation and crystallization of relatively soluble dissolved solids at the heat transfer surfaces.	Deposits left behind on the heating surface with the formation of steam bubbles.	
Increasing the concentration of suspended solids in the boiler water due to inadequate blowdown.	More solids in contact with the heat transfer surfaces increasing the potential for scale formation and carryover.	
Accumulation of iron and copper oxides from corrosion by-products entering the boiler from the preboiler system or transported with the return condensate.	Form deposits. Act as binders for other insoluble solids in the boiler water, further increasing deposit tendencies. Contribute to electrolysis corrosion.	
Oil or process contamination can adhere to boiler surfaces or increase adherence of boiler solids.	Leads to boiler deposit formation.	

2.4 Juice Clarification

Juice clarification reduces the number of insoluble particles in the raw juice resulting in a clear juice ready for crystallisation. This step in the sugar factory involves the removal of bagacillo from the raw juice, heating of the juice and lastly the removal of suspended particles from the raw juice. Clarification produces a clear juice and a waste product, *viz.* mud. The mud can be reworked to extract any remaining sucrose.

2.4.1 Screening

Screening is required to remove the larger insoluble solids from the raw juice after the diffuser or milling tandem (Rein, 2007; Meadows, 1996). The remaining smaller particles are removed in clarification (Rein, 2007). There are two types of screens in use in the South African sugar industry, the DSM Screen™ and the ‘Contra-Shear’ cylindrical screen (Meadows, 1996). The raw juice is passed over a screen of wedge-wires with apertures of approximately 0.75 mm (Meadows, 1996). Bagasse particles which are larger than the spaces between the wires remain on the screen and are removed by the backup of more bagasse and the slope of the screen (Rein, 2007). The bagasse that remains after screening is termed *cush* and can be returned to the mill or diffuser where remaining moisture can be extracted (Rein, 2007). In some diffusion sugar factories screening is not undertaken due to the low percentage of fibre in the raw juice (Meadows, 1996). Meadows (1996), however, reports that factories that do not have screens experience problems with carry-over of bagacillo in the clear juice, sand erosion and blockages in the juice heaters. Meadows (1996), reports that similar problems would occur when using DSM Screens™ if there is screen wear and hence an increase in aperture size. The ‘Contra-Shear’ screens may not experience such problems provided the screen is kept clean (Meadows, 1996).

It is important that the screens are kept clean, if not, they provide an ideal site for microorganism growth (Rein, 2007). An indication of microorganism growth is slime build up as a result of the microorganism *Leuconostoc mesenteroides* (Rein, 2007). This is only an indicator microorganism and there are many others that may cause serious sucrose losses (Rein, 2007).

2.4.2 Heating

The purpose of heating is to bring the temperature of the raw juice slightly above 100°C to allow for effective flashing prior to clarification (Meadows, 1996). Flashing removes air particles attached to the non-soluble particles enhancing the rate of settling in the clarification tanks (Meadows, 1996). The heating process is thus required to increase the temperature of the raw juice from ambient temperature, if a milling tandem is used, or from 60 °C in the case of a diffuser (Rein, 2007). Once the juice has reached the required temperature it is flashed in a flash tank to remove trapped air and to ensure a constant temperature juice to the clarifier (Rein, 2007). The most commonly used heat exchangers are shell or tubular heaters, however, the more modern choice are plate heaters (Meadows, 1996).

An operational problem associated with heat exchangers is the build up of scale on the inside of tubes or on the plates and can constitute a significant resistance to heat transfer within a few days (Rein, 2007). This scaling is very similar to that encountered in the evaporators as is discussed in Section 2.5.1 and 2.5.4. A major cause of increased scaling is an increase in the silica content of the raw juice. Increased silica in the raw juice is mainly as a result of an increase in the amount of sand that enters the sugar factory (Rein, 1990). Rein (1990) reports in a study at Felixton Mill that the increase in sand entering the factory was attributed to stale cane as a result of delays due to the rain. Tests conducted by James *et al* (James *et al.*, 1978) show that the scaling results in a reduction in the heat transfer coefficient and thus an increase in the time required in heating the raw juice to the required temperature.

2.4.3 Clarification

The purpose of clarification is to remove suspended matter providing a clear juice of minimum turbidity, colour and low calcium content (Rein, 2007). The most common method of clarification in sugar factories today is defecation (Rein, 2007). This involves the addition of lime to the raw juice which forms flocs that trap suspended matter (Rein, 2007). As the particles gain mass they settle to the bottom of the tank where, after forming mud, can be drained out (Rein, 2007). The mud that is formed is filtered or passed back to the diffuser in order to extract more sucrose. This process is described in Section 2.4.4.

There are many types of clarifiers in use, the main design objective is to increase the surface area available for settling and thus reduce the residence time and improve the clarity of the resultant juice. One of the most successful continuous clarifiers that is available in the sugar industry is the SRI type (Sugar Research Institute, Australia) Clarifier (Rein, 2007).

The solids settling rate in the clarifier is dependent on the Brix content of the raw juice (Rama *et al.*, 2006). In this case the Brix content of the raw juice is referring to the total dissolved solids in the solution (Rein, 2007). If the amount of imbibition water used in the diffuser is reduced, the Brix level in the clarification process increases (Rama *et al.*, 2006). It has been reported that the solids settling rate will be impaired if the level of the Brix rises above 15.0°Bx (Rama *et al.*, 2006).

The filterability of raw melt in the sugar refinery after the production of a raw sugar may be affected by the impurities remaining in the sugar after clarification (Mkhize, 2003). This is mainly due to the high loads of suspended solids and turbidity (Mkhize, 2003).

Problems in the clarification process can also be attributed to operational errors. Mkhize (2003) reports that one of the causes of poor clarification could be overliming of the raw juice as a result of poor pH control. Poor pH control could be attributed to pH probe failure, poor lime quality, lime preparation problems and lime dosing pump problems (Mkhize, 2003). In the case of poor liming Mkhize, (2003) reports that high juice turbidity could last at least 20 minutes and in most cases it lasted for almost three hours (Mkhize, 2003).

The frequent start up and shut down of the factory can also cause high turbidity problems (Mkhize, 2003). This becomes more of a problem towards the end of the season when the supply of cane to the factory is unsteady (Mkhize, 2003). The effects of inconsistent operation of the factory on the clear juice could last a couple of hours.

Phosphates in the raw juice prior to the addition of lime are required to achieve good clarification (Rein, 2007). The phosphates react with the lime to form a precipitate that constitutes an important part of the floc precipitated in the juice (Rein, 2007). A phosphate level of 200 – 300 mg/kg juice has been suggested as the minimum for effective precipitation (Rein, 2007). Phosphates occur naturally in the cane, however, when the concentration drops below the minimum, the addition of inorganic phosphates is required (Rein, 2007). Mkhize

(2003) reports that the determination of phosphate levels in the sugar factory is a problem which often leads to poor clarification.

During clarification there is a possibility of mud carryover. In the case of mud carryover there is an increase in colour of the clear juice (Sahadeo *et al.*, 2002). It is reported that the affinated sugar that has been contaminated by the mud carryover also experiences a significant increase in calcium and phosphate levels (Sahadeo *et al.*, 2002). The ash levels in both the syrup and molasses also increase after a case of mud carryover (Sahadeo *et al.*, 2002).

Carryover can also contain fine suspended matter from the clarifier. Dextran in the raw juice has been identified as the cause of the fine suspended matter (Ravno and Purchase, 2005). The dextran acts a protective colloid and inhibits coagulation, therefore preventing the entrapment of fine matter in the mud (Ravno and Purchase, 2005). The fine matter has an effect on the quality of the sugar, increasing the ash content and increasing its colour (Ravno and Purchase, 2005). The subsequent processing of the low quality sugar in the sugar refinery is impeded (Ravno and Purchase, 2005). More specifically the suspended matter causes poor filtration of melts and hence a reduction in throughput (Ravno and Purchase, 2005). If the reduction in through put is substantial refiners may seek alternative sources of raw sugar (Ravno and Purchase, 2005).

2.4.4 Filtration

The mud from the clarifier still contains a certain amount of raw juice. In order to recover the juice the mud is passed through a filtering system. Bagacillo, fine bagasse particles, are added to the mud from the clarifier aiding in the filtration of the mud (Rein, 2007). The bagacillo is added in a mud mixer. Here the mud is also prepared to optimise the permeability of the filter cake (Rein, 2007). Ideal conditions for permeability are at temperatures above 75 °C and at pH levels slightly lower than 8.5 (Rein, 2007). The optimal pH can be achieved by adding milk of lime or lime saccharate (Rein, 2007). Additional flocculent may also be added to once again increase porosity and control the viscosity of the filter cake (Rein, 2007). The mixture is transferred to either a plate and frame filter press or more commonly a rotary drum vacuum filter (Rein, 2007). Wash water is used to remove any remaining sucrose from the filter cake

(Rein, 2007). The filtrate from the process is returned to the raw juice from the diffuser or mill (Rein, 2007).

Mud recycling is a relatively new concept in which mud from the clarifiers is passed back into the diffuser (Rein, 2007). The cane fibre acts as a filter removing the mud while the sucrose that was contained within the mud has another opportunity for extraction (Rein, 2007). Impacts of mud recycling on the diffuser are outlined by Lionnet *et al.* (2005). Lionnet (2005) found that mud recycling changed the pH profile in the diffuser since the mud is generally at a higher pH than that of the clear juice in the diffuser (Lionnet *et al.*, 2005). Secondly it was found that the residual flocculent from the clarification process caused a decrease in the percolation rate of the diffuser (Lionnet *et al.*, 2005).

2.5 Juice Evaporation and Crystallisation

The most important process in the sugar factory is the removal of large amounts of water and the subsequent crystallisation of the sucrose. The quality of the final sugar crystal is affected by the method of crystallisation, the stage at which the crystal was formed and the impurities present in the syrup. Before crystallisation can take place the clear juice must first be reduced to form syrup and be clarified once more, however this time by flotation.

2.5.1 Evaporation

In order to create syrup ready for crystallisation a substantial amount of water must be evaporated from the clear juice. The evaporation process reduces the water content of the clear juice to a concentration of 65 to 68 % dissolved solids thus forming syrup (Rein, 2007). This is just below the crystallisation point of syrup thus enabling storage in liquid state (Rein, 2007). Evaporation is undertaken in multiple effect evaporators using steam as the energy source (Rein, 2007). Most of the energy produced from the boilers is used in evaporation thus the efficiency of the process has a great effect on the overall energy efficiency of the factory (Rein, 2007).

At high temperatures the reducing sugars that are present in the clear juice easily change to increase the colour of the resultant sugar. The increase in colour is more pronounced when high viscosity syrup is processed (Rein, 2007). It is thus more desirable to have a lower

temperature profile across the evaporators and heat the high viscosity syrup at the lowest temperature (Rein, 2007). For this reason cocurrent flow of the clear juice and steam is used in the sugar industry (Rein, 2007). Cocurrent flow through the evaporator also reduces the residence time of the dissolved solids thus minimising the time for degradation of the sucrose (Rein, 2007).

Optimum performance is achieved when the steam supply to the evaporators is constant thus ensuring steady operation (Rein, 2007). In addition to constant steady operation the level of juice inside the tubes should be 25 to 50 % of the maximum height (Rein, 2007).

Scale in evaporators affects the heat transfer and hence the efficiency of the evaporator (Rein, 2007). A major component of scale is silica which is deposited as the Brix increases across the evaporator train and pans (Walthew *et al.*, 1998). The amount of silica present in the clear juice is determined by the quality of cane entering the factory and the pH of the imbibition water used in the diffuser (Walthew *et al.*, 1998).

2.5.2 Condensers and vacuum equipment

Condensers and vacuum equipment are required to condense water vapour produced from the evaporators (Rein, 2007). To induce cooling the vapour from the evaporators comes into direct contact with the cooling water (Rein, 2007). Common types of condensers are the countercurrent multi-tray condenser and rain type condensers (Rein, 2007). An alternative is the multi-jet condenser which injects a fine mist of water into the flow of the warm vapour (Rein, 2007). The difference in temperature between the vapour and the cooling water determines the amount of cooling water required (Rein, 2007). The vacuum equipment is used to remove the incondensable gases from the condensers (Rein, 2007). In order to reduce the temperature of the cooling water spray ponds or cooling towers are used to reject the heat to the atmosphere (Rein, 2007).

2.5.3 Syrup Clarification

Syrup clarification is usually required when producing sugar for direct consumption after the sugar factory (Rein, 2007). Syrup clarification reduces the suspended solids content and the colour of the final sugar crystals (Rein, 2007). Syrup clarification uses clarification by

floatation. Flotation clarification is preferred because of the high viscosity of the syrup does not allow for clarification by settlement (Rein, 2007). Syrup clarification involves the addition of a polyacrylamide flocculant and then the aeration of the syrup (Rein, 2007). Other chemicals such as sulphates or phosphates can be added to achieve a certain sugar quality (Rein, 2007). The flocculant causes the suspended particles to combine allowing the fine air bubbles to carry these particles to the surface of the clarifier (Rein, 2007). The layer of scum that forms on the top of the clarifier is continuously removed while clear syrup is drained off the bottom of the clarifier (Rein, 2007).

The temperature of the syrup affects the efficiency at which the suspended solids are removed. It is suggested that there are improvements in the removal of suspended solids up to a temperature of 85 °C (Rein and Cox, 1987).

Syrup clarification reduces the final viscosity of the molasses by about 25 % (Rein and Cox, 1987). The reduced viscosity allows for higher Brix massecurites and the use of less steam and water on the centrifugals (Rein and Cox, 1987).

2.5.4 Crystallisation

Crystallisation of sucrose occurs when the when the sugar solution becomes supersaturated. The objective of crystallisation is thus to bring the syrup into the supersaturated state and control it at a specific concentration to achieve a steady rate of crystallisation (Rein, 2007). The rate of crystallisation is dependent on the supersaturated coefficient, y , calculated as shown below:

$$y = \frac{W_s/W_w}{(W_s/W_w)_{sat}} \text{ (Rein, 2007)}$$

Where: W_s = concentration of sucrose expressed as g/100 g solution
 W_w = mass of water expressed as g/100 g solution

Rein (2007) recommends that the solution should be held at a supersaturated coefficient of 1 - 1.2. In this zone crystallisation growth will only occur on existing crystals, no new sugar nuclei will form (Rein, 2007). Thus the amount of crystallisation that occurs can be controlled.

The crystallisation of the sugar solution usually takes place by passing the solution through three pans, each pan crystallising a lower grade of syrup. The amount of crystallisation which can be carried out in the pan is dependent on the ability of the massecuite to flow out the pan (Rein, 2007). Before this occurs the massecuite is drained out of the pan and is centrifuged to remove the sugar crystals and the remaining molasses is fed into the next pan (Rein, 2007). This process is repeated again until a final molasses is produced. The number of steps required to achieve final molasses is dependent on the purity of the syrup (Rein, 2007).

During crystallisation in the A pan there is a possibility of contamination by airborne bagacillo (Simpson and Davis, 1998). If the raw sugar contains a high quantity of bagacillo problems will occur further down the line in the sugar refinery, more specifically during refinery filtration (Simpson and Davis, 1998). Bagacillo in the raw sugar is also caused by poor flashing of the raw juice during clarification (Simpson and Davis, 1998).

The conditions in a crystalliser are suited to the build up of sugar or encrustation on the walls of the crystalliser (Rein, 1990). To prevent excessive encrustation the vacuum pans are streamed out or cleaned on a routine basis (Rein, 1990). When encrustation becomes severe it can break off the walls and block tubes and outlets (Rein, 1990). Encrustation is found more in the higher grade pans, *i.e.* the A-pan (Rein, 1990). The rate of encrustation is therefore affected by the purity of the massecuite being boiled (Rein, 1990). For example the C-pan only needs to be cleaned out approximately every 38 weeks, while the A-pans need to be cleaned out after a few weeks (Rein, 1990).

Other factors that affect the rate of encrustation are the crystal surface area to unit volume, the supersaturation in the mother liquor, the rate of evaporation, and the viscosity of the massecuite (Rein, 1990). The rate of evaporation influences the amount of splashes that hit the walls of the crystalliser tank and the viscosity affects the amount of time the massecuite takes to run down the wall (Rein, 1990). Increasing the time the massecuite remains on the wall increases the possibility for crystallisation (Rein, 1990). In addition to these factors the number of crystals and the size of the crystals also effects encrustation (Rein, 1990). The higher the concentration of crystals the higher the possibility that they will stick to the wall of the crystalliser and the smaller they are the easier it is for them to attach (Rein, 1990).

The shape of the crystal that is formed during the crystallisation process affects the efficiency of centrifuging. Low raw juice quality results in the distortion of sugar crystals, for example the elongation of crystals and needle grains (Smits and Blunt, 1976). The deformed sugar grain impedes molasses exhaustion in the centrifugals (Smits and Blunt, 1976). The fragile shape of the crystals causes them to break easily in the centrifuge therefore resulting in the loss of sugar through the screen (Ravno and Purchase, 2005). The poor quality raw juice also causes an increase in massecuite viscosity and therefore rapid blinding of centrifugal screens (Smits and Blunt, 1976). In order to counteract the poor molasses removal in the centrifuge additional wash water is required (Ravno and Purchase, 2005). An increase in the wash water results in an increase in loss of sucrose to the molasses and increase in the amount of steam required for evaporation of the water in subsequent pans (Ravno and Purchase, 2005; Ried, 2006). Impurities in the raw juice also block the crystal faces causing incomplete crystallisation in the time available (Ravno and Purchase, 2005).

To aid centrifuging the crystals should be large and uniform in size (Ravno and Purchase, 2005). The larger the crystals are the smaller the surface area to volume ratio becomes hence allowing easier molasses removal (Ravno and Purchase, 2005). The crystals should also be of similar size. This ensures a lower packing density in the centrifugal and hence maintains pathways through which the massecuite can flow (Ravno and Purchase, 2005).

Scale build up in the crystalliser causes a reduction in the heat transfer between the clear juice and heating surfaces (Eggleston and Monge, 2005). This is particularly a problem in the later evaporators, *i.e.* B and C pan evaporators. As the inorganic ions in the later evaporators become supersaturated they precipitate out and are deposited on the heating surfaces (Eggleston and Monge, 2005). Scaling in the crystallisers also causes an increase in the loss of sucrose (Eggleston and Monge, 2005). Eggleston and Monge (2005) report that the reduced heat transfer results in an increased retention times and decreased flow rates. In order to compensate for this the heat juice temperature is increased. An increase in the juice temperature however increases the conversion of sucrose to glucose and fructose (Eggleston and Monge, 2005; Eggleston and Monge, 2007).

2.6 Cooling Crystallisers

Cooling crystallisers are designed to maximise crystallisation after the crystallising pans. The massecuite that leaves the vacuum pan is supersaturated and hot hence further crystallisation can be induced on cooling (Rein, 2007). Cooling crystallisation is undertaken prior to centrifuging in either batch or continuous crystallisers (Rein, 2007). It is preferable to operate a continuous cooling crystalliser as it requires less labour and automation (Rein, 2007). The massecuite is cooled by coils through which cooling water is passed (Rein, 2007). The operational objectives during cooling crystallisation are to ensure the required residence time and target temperature on leaving the crystalliser is achieved (Rein, 2007). The correct outlet temperature of the massecuite is attained by controlling the rate of flow of cooling water through the cooling pipes (Rein, 2007).

Problems may occur in the cooling crystalliser if the Brix of the solution is high or the massecuite is cooled down further than normal as a result of mill breakdowns or particularly cold weather (Rein, 2007). Lower than normal temperature results in a massecuite that is too viscous for the operation of the mixing drives. A solution to the problem is to either increase the temperature of the cooling water or blend molasses into the cooling crystallisers (Rein, 2007).

2.7 Centrifuging

Centrifuging removes the liquid that surrounds the crystals after crystallisation. It utilises a centrifugal force which drives out the molasses from between the sugar crystals. Additional wash water can be added to the centrifuge to remove the remaining liquid from the crystals (Rein, 2007). Centrifugals are classified into continuous and batch operation. The continuous centrifugals are simpler, easier to operate and have lower maintenance costs (Rein, 2007). However they tend to break the sugar crystals on discharge (Rein, 2007). The batch centrifugals result in the extraction of a higher quality sugar crystal (Rein, 2007). The continuous centrifugal is therefore more suited to C massecuite where the quality of the crystal is not of too much concern (Rein, 2007). Batch centrifugals are more suited to A-pan and B-pan massecuite where the resultant sugar crystals should be of a market standard (Rein, 2007).

The method of operation of the batch centrifugal is important. For example the feed to the centrifuge should form an even layer of massecuite on the walls of the basket (Rein, 2007). The speed should be enough so that the massecuite does not purge too quickly and to prevent uneven distribution of the massecuite (Rein, 2007).

As discussed in Section 2.5.4 the presence of dextran and other impurities in the raw juice causes deformation of the sugar crystals. This makes them susceptible to breaking during centrifuging and the subsequent blockage of the screens (Smits and Blunt, 1976).

2.8 Drying

The drying of the raw sugar is the last process in the sugar factory before it is sold to the market or to the sugar refinery. Drying is required to ensure free flowing characteristics are obtained for handling purposes and to meet customer specifications (Rein, 2007). In addition to attaining the physical properties required by the customer, drying is also required to prevent sucrose loss as a result of microbiological or chemical degradation (Rein, 2007).

There are a number of different designs of sugar driers that are in operation in sugar factories. Examples of sugar drier designs are the rotary cascade, multitube drier-cooler, rotary louver, and the fluidized bed (Rein, 2007). The basic principle behind the drying process is to pass dry warm air through a loosely packed or falling layer of raw sugar. In the rotary cascade and multitube drier, fins are used to lift and pour the raw sugar as it passes through a cylinder or set of cylinders (Rein, 2007). The action exposes the raw sugar to the warm air that is drawn through the cylinder and also serves to break up any solid groups of crystals (Rein, 2007). The fluidized bed drier uses forced air to fluidise the sugar bed and thus allow for efficient drying of each sugar crystal (Rein, 2007). While the rotary louver uses a combination of the fluidised bed and the rotary cascade to induce drying (Rein, 2007). The degree to which the sugar is dried can be expressed by the Safety Factor (SF) as shown below. In South Africa it is suggested the SF be maintained below 0.23 for all grades of sugar (Rein, 2007)

$$SF = \frac{w_w}{100 - w_w} = \frac{w_w}{w_{NS} + w_w} \text{ (Rein, 2007)}$$

Where: w_w = water (moisture) content

w_s = sucrose content determined by polarization and

w_{NS} = nonsucrose content of the sugar

The units for all the above are g / 100 g sugar..

There are thus three mechanisms that take place during drying. The first is the evaporation of water that is governed by the vapor pressure difference between the film and the surrounding air (Rein, 2007). The second is the rate of diffusion of water molecules through the film on the surface of the crystal and lastly the crystallisation of sucrose molecules in the film as amorphous sugar or onto the sugar crystal (Rein, 2007). The majority of the water is evaporated in the first stage and therefore it is more important to focus on that area (Rein, 2007).

It is preferable to remove syrup and molasses during the centrifuging process as it is far more efficient than the subsequent removal of water by evaporation in the driers (Farag, 1977). Therefore in the case of inadequate drying, the amount of wash water in the centrifugal should be increased (Farag, 1977). A film of water is far easier to remove than a molasses film. The impurities contained in the molasses retard the crystallisation required in order to release moisture (Farag, 1977).

3. DISCUSSION AND CONCLUSION

The compilation of the review has been sourced from various studies over the past approximately 30 years. It is apparent that there is a lack of integration of these studies. The project will therefore create a set of tools which incorporates the engineering principles controlling the efficiency of sugar production. With the addition of soft system analysis tools one would be able to apply the tools to create a procedure for sugar factory optimisation.

The literature indicates that there are many influences on the production of raw sugar. Some of the processes are relatively closed systems with respect to cause and effects *i.e.* their the cause and effects are experienced only within that process. There are, however, processes that are affected by factors up the line of production as well as down the line of production in the sugar factory. For example the extraction of sucrose from the cane bed can be improved by increasing the amount of imbibition water. The trade off for an increased sucrose extraction is a higher energy requirement for the evaporation of water from the clear juice. The complexity of the interactions increases rapidly and therefore requires system analysis tools to understand.

A simple table of influences has been compiled. Table 3.1 contains the main causes and problems within the sugar factory and which areas within the factory they affect. A single cause can result in a number of problems. These are contained within the same bracket of the cause. By counting vertically the occurrences of problems occurring within each process it is possible to determine which processes are more vulnerable. The horizontal count identifies which cause influences the highest number of processes.

The processes that scored the highest are boiling, diffusion and crystallisation. Problems in the boiler were attributed mainly to scaling. These could be grouped into one problem hence the boiler only experiences two problems, scaling and low pH as a result of sucrose breakdown. The diffusion process is affected by poor percolation and hence flooding and degradation of sucrose due to stoppages. Crystallisation is affected mainly by scaling and crystal growth properties.

The number of times a cause affects a process are counted horizontally on the right hand side of Table 3.1. This helps to identify process that have a major effect throughout the sugar factory. It is apparent from the table that scaling has a major effect throughout the factory, influencing boilers, heaters, evaporators and crystallisers. Most of the other causes affect only one process in the sugar factory. With the help of this tool it is possible to better identify areas which require close monitoring in the sugar factory.

By analysing the cause and effects relationships within a generic sugar factory it is apparent that there are opportunities for improvement within the sugar factory. These need to be compiled into a cognitive map to allow for comprehension. The cause and effects within the sugar factory system can then be added to the larger overall sugar production system and hence enhance the understanding of the system.

Table 3.1 Table of influencing properties

Cause	Problem			Process Affected														Count			
				Knifing	Shredding	Milling	Diffusion	Boilers	Screening	Heating	Clarification	Filtration	Evaporation	Crystallisation	Cooling Crystallisers	Centrifugals	Drying				
Incomplete Burning	Dextran	Viscosity																✓	1		
		Crystal Shape												✓	✓				2		
Stale Cane	Increase in Soil	Suspended Solids	Poor Percolation				✓												1		
Rainy Weather	Increase in Soil	Suspended Solids	Poor Percolation				✓												1		
	Increase in Sand	Wear						✓											1		
		Scale						✓		✓			✓	✓					4		
		Carryover									✓								1		
Starch	Viscosity																	✓	1		
Fibre	Inhibit Crystal Growth													✓					1		
Soil	Wear					✓					✓								3		
Extraneous Matter	Wear	Bhnt knives		✓	✓														2		
			Pulping																1		
			Poor Percolation				✓												1		
			Flooding				✓												1		
Lack of Cleanliness	Fermentation of sugar																		1		
Sucrose	Breakdown	Lowers pH						✓											1		
		Carbonaceous Deposits						✓											1		
Silica	Scale							✓		✓			✓	✓					4		
Overliming in Diffuser	Poor Percolation						✓												1		
pH above 8.5 in Diffuser	Silica	Scale						✓		✓			✓	✓					4		
Start Up and Shut Down	Fermentation of sugar																		0		
	High Turbidity Juice										✓								1		
							Count	1	2	0	6	6	0	3	3	0	3	5	1	1	1

4. PROJECT PROPOSAL

The project will analyse the cause and effect interactions of the Umfolozi Sugar Mill. The mill is located 4 km south of Mtubatuba. The project will form part of a larger analysis of mill vulnerabilities to upstream properties of the sugarcane supply chain.

4.1 Research Question

The different aspects of the production of sugar in South Africa have developed in relative isolation (Gaucher *et al.*, 2003). There are therefore opportunities that exist for the optimisation of the production system. The processes that exist within the sugar factory have been well researched throughout the world. There has, however, been a lack of integration of this research into useful tools that can be applied to the factory in order to improve production. The tools that are to be created cannot be applied without the consideration of the soft issues that surround the engineering principles. There is therefore need for further integration of the engineering tools with soft system integration tools. There research question that follows is thus:

How can engineering cause and effect interactions to be incorporated into the larger sugarcane supply chain system?

4.2 Rationale

The processes within the sugar factory are required to accommodate large fluctuations in the quality of the incoming cane sugar. The fluctuations in the sugarcane are attributed to a large number of factors prior to the sugar factory. These causes and related problems have been identified. Solutions have been formulated to counter act these problems however effective application of the solution has yet to be undertaken. Lack of application may be as a result of the complex multi stakeholder environment in with the South African sugar industry operates (Engelbrecht *et al.*, 2009).

There is therefore scope for the application of a systems analysis tool that can identify areas in the sugarcane supply chain that can unlock the systems full potential. This system should be

integrated into the processes of the sugar factory thus allowing a clear view of the supply chain from the growing of the crop to the production of a high quality raw sugar.

4.3 Aims and Objectives

This research aims to demonstrate an overarching heuristic that will identify and unlock relatively small, but relevant, system constraints and opportunities in the sugarcane production and processing chain of the Umfolozi Sugar Mill. The heuristic considers both hard and soft aspects of the system including value adding, material handling, stakeholder collaboration, information sharing and innovation. The objectives will be realised and studied in the particular area that the case study is conducted.

4.4 Methodological Approach

A literature review will first be conducted on the cause and effect relationships that exist within the sugar factory.

The sugar factory will first be analysed from a global stand point. Once an understanding of the sugar factory and mill has been gained the following steps will be undertaken as listed.

- Systemic problem areas will be identified and described through network analyses.
- One pertinent problem area will be selected and a set of tools will be compiled to systematically expose and unlock it.
- Where possible, these tools will be implemented and suitable performance metrics will be selected, monitored and communicated to the relevant stakeholders. The aim will be to develop a system that can continue to evolve into a more efficient state even after the researchers have left the area.
- Value-adding opportunities among neighbouring industries in the mill area will be explored. This will be done with an aim of compiling an inventory of technologies that are already in existence, and that can be implemented with relative ease.

The Gantt chart in Figure 4.1 gives the approximate time frame of the various tasks of the project.

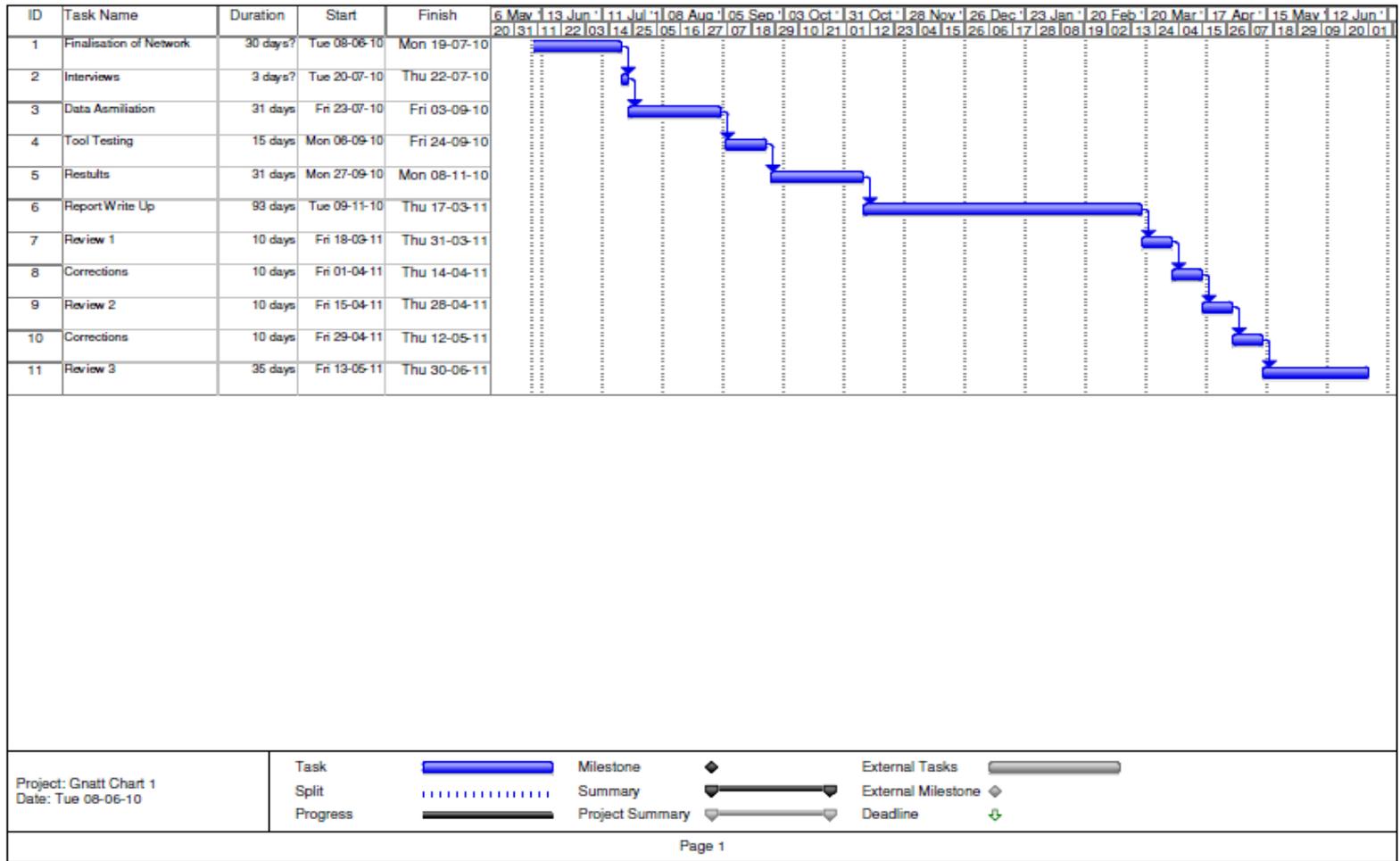


Figure 4.1 Gantt chart of project.

4.5 Resources Required

The necessary resources, to facilitate transport, computing requirements, which include Pajek (a network analyses tool) and also an interview interface to help stakeholders weigh up different system pathways, and accommodation if needed, are provided. The funding for the project is secured within a research contract with the South African Sugar Research Institute (SASRI).

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