Another problem faced by operators of sugar refineries is that process equipment is prone to fouling due to the precipitation/deposition of sugar and impurities from the sugar cane juice on the process equipment. Examples of impurities include organic impurities such as proteins and inorganic impurities such as calcium- and silicon-containing minerals. Consequently, the process has to be periodically stopped to manually clean the process equipment to maintain the quality and output of the final product.

Attempts to avoid browning of the sugar cane juice include performing the evaporation at a lower temperature. However, this extends the processing time due to the reduced rate of evaporation and still requires periodic interruption of the process to allow manual cleaning of the process equipment.

It would be desirable to provide a process for concentrating process fluids, such as sugar cane juice, which reduces process down time.

SUMMARY ~~OF THE INVENTION~~

The present ~~invention~~disclosure provides an improved process and apparatus for concentrating a process fluid.

The present ~~invention~~ disclosure seeks to achieve this at least in part by operating under optimal conditions that concentrate the process fluid while reducing fouling of the process equipment. This may involve controlling the temperature of the process fluid.

The present ~~invention~~ disclosure may proactively mitigate the build-up of fouling by providing improved drift elimination in the mass transfer medium (e.g. air) line and/or evaporation-fill-less evaporation of the carrier fluid (e.g. water) in the process fluid.

The present ~~invention~~disclosure also incorporates an automated cleaning system that allows cleaning of the liquid line including at least one heat exchanger. The automated cleaning system also allows the present ~~invention~~disclosure to handle process fluids that contain substances that cause fouling or to avoid manual cleaning of the process equipment.

In this specification, mass transfer medium refers to a fluid, typically air, which facilitates mass transfer of a carrier fluid (e.g. water) from a process fluid stream into the mass transfer medium. Heat transfer may occur during this process.

In this specification, heat transfer medium refers to a fluid, for example water, which receives heat from or transfers heat to a process fluid.

The cleaning system may include one or more storage tanks which store anti-fouling reagents, valves and pumps that circulate the anti-fouling reagents through the apparatus in accordance with a cleaning protocol to de-foul the process equipment.

The cleaning protocol may be initiated when predetermined process variables deviate from their threshold ranges.

The cleaning protocol may be initiated when threshold ranges of predetermined process variables are exceeded.

The cleaning protocol can be run on a regular timed cycle or when a build-up of sludge/scale is detected.

The apparatus may include a controller in electrical communication with a plurality of sensors which monitor process variables at various parts of the process. Suitably, the controller is a Programmable Logic Controller.

The apparatus may include one or more of pressure, flowrate, temperature, humidity and level sensors.

The apparatus may include pressure and flowrate sensors to detect fouling, for example in the process fluid, water and air lines connected to an evaporator or heat exchanger(s) of the apparatus. When the sensors detect the pressure or flowrate deviating from a predetermined threshold value/range, a controller initiates a cleaning protocol to de-foul the apparatus.

Whilst the present ~~invention~~disclosure is particularly suitable for processing sugar cane juice, the present ~~invention~~disclosure is equally suitable for other applications including processing waste water and producing distilled water as process byproduct. Accordingly, whilst the present specification focuses primarily on the application of the ~~invention~~disclosure to processing sugar cane, it is to be understood that the ~~invention~~disclosure is not limited to that application.

The present ~~invention~~disclosure is also suitable for performing zero-liquid discharge of various process fluids, for example wastewater from drying ponds, and in-process fluid streams.

The cleaning system of the present ~~invention~~disclosure is equally applicable to energy-saving configurations which may comprise pre-cooling/energy recovery heat exchangers in any one of more of the process fluid, air and water-lines which only affect the energy efficiency of the process, and not the anti-fouling qualities.

The present ~~invention~~disclosure provides a method of concentrating a process fluid, including a carrier fluid, including:

(a) maintaining a process fluid at a predetermined temperature value/range;

(b) evaporating the carrier fluid from the process fluid to produce a concentrated process fluid;

(c) monitoring at least one process variable of steps (a) or (b) to detect fouling formed in either step (a) or (b); and

(d) initiating a cleaning protocol if the process variable deviates from a predetermined value/range to reduce the fouling formed.

In an aspect, there is provided a method of concentrating a process fluid, including a carrier fluid, including:

(a) maintaining a process fluid at a predetermined temperature value/range;

(b) evaporating the carrier fluid from the process fluid in an evaporator to produce a concentrated process fluid and an effluent mass transfer medium;

(c) monitoring at least one process variable of steps (a) or (b) to detect fouling formed in either step (a) or (b);

(d) initiating a cleaning protocol if the process variable deviates from a predetermined value/range to reduce the fouling formed; and

(e) directing part of the effluent mass transfer medium into a drift chamber located downstream of the evaporator having a plurality of run-off outlets to remove entrained process fluid prior to returning the mass transfer medium to the evaporator.

The process fluid encompasses homogeneous solutions and heterogenous mixtures obtained from a process (e.g. sugar solution from crushing of sugar cane or an effluent waste stream from a sugar refinery).

The carrier fluid may be a solvent that can dissolve a solute, or the liquid medium of a suspension or slurry. Suitably, the carrier fluid is water.

The mass transfer medium may be a gas. Suitably, the mass transfer medium is air.

When the mass transfer medium is a gas, the method may include bubbling the gas through water to humidify the gas entering the evaporator.

When the mass transfer medium is a gas, the method may include spraying the process fluid onto evaporation fill material.

Step (d) may include initiating the cleaning protocol if the pressure or flow rate deviates from a predetermined value/range to reduce fouling in a heat exchanger or evaporator.

Suitably, evaporation occurs at a temperature that does not result in degradation of the process fluid or an increase in fouling of the process equipment. For example, when processing sugar cane juice, evaporation is performed at a temperature ranging from 20-40°C which was determined to avoid browning of the sugar cane juice and minimise deposition of sugar onto process equipment. In other ~~embodiment~~examples, evaporation occurs under ambient environmental conditions.

The process fluid may be in-process liquids such as sugar cane extract or wastewater.

The process fluid may be maintained at a temperature not exceeding 40°C using a heat exchanger. This ensures that the process fluid is at a temperature that does not cause excessive fouling or degradation of the process fluid when

it is concentrated in an evaporator. For example, if the process fluid is a sugar solution, the temperature is maintained at a maximum of 20-40°C to ensure that the polysaccharides in solution do not degrade into di- or monosaccharides, or to minimise caramelisation from occurring.

The process fluid may be maintained at the predetermined temperature value/range via counter current heat exchange.

The present ~~invention~~disclosure also provides a method of producing a sugar concentrate from sugar cane, including:

(a) obtaining a sugar-containing extract from sugar cane;

(b) maintaining the extract at a predetermined temperature value/range;

(c) clarifying the extract in the absence of added lime;

(d) evaporating water from the extract to form a sugar concentrate;

(e) monitoring a process variable of step (b) or (d) to detect fouling formed in either step (b) or (d); and

(f) initiating a cleaning protocol if the process variable deviates from a predetermined value/range to reduce the fouling formed.

In another aspect, there is provided a method of producing a sugar concentrate from sugar cane, including:

(a) obtaining a sugar-containing extract from sugar cane;

(b) maintaining the extract at a predetermined temperature value/range;

(c) clarifying the extract in the absence of added

lime;

(d) evaporating water from the extract in an evaporator to form a sugar concentrate and an exiting air stream;

(e) monitoring a process variable of step (b) or (d) to detect fouling formed in either step (b) or (d);

(f) initiating a cleaning protocol if the process variable deviates from a predetermined value/range to reduce the fouling formed; and

(g) directing part of the exiting air stream into a drift chamber located downstream of the evaporator having a plurality of run-off outlets to remove entrained non-vaporised sugar cane extract droplets prior to returning the air stream to the evaporator.

Step (a) may involve crushing sugar cane to obtain the sugar-containing extract (i.e. sugar cane juice). Suitably, the sugar-containing extract is formed by mixing the crushed sugar cane with water.

increase in the PD (at the specific flow rate on the specific fluid).

The method may include stopping flow of process fluid into an evaporator before initiating the cleaning protocol. Suitably, the method may include re-directing the process fluid into a storage tank before initiating the cleaning protocol. This ensures that the anti-fouling reagents do not mix with and contaminate the process fluid.

The cleaning protocol can trigger a longer self-clean and/or the release of anti-fouling reagents with stronger cleaning properties (e.g. warmer water, more concentrated acid or basic solution).

For a 250 L/day laboratory unit, the predetermined pressure value/range of the heat exchanger may range from 5-50 kPa, preferably ranging from 10-45 kPa, more preferably 45kPa. Suitably, the predetermined pressure value/range may be linearly scalable depending on the capacity of the apparatus. The predetermined pressure value/range may be dependent on the heat exchange method.

For a 250 L/day laboratory unit, the predetermined value/range of the mass transfer medium flowrate of the evaporator may range from 10-20 L/min, preferably 15 L/min. It was determined that fouling of the evaporator would reduce the mass transfer medium across the evaporator. As such, once the flowrate is reduced below a threshold limit, the controller initiates the cleaning protocol. Suitably, the threshold limit may be a drop of at least 0.5 litres/min. The predetermined value/range of the mass transfer medium flowrate of the evaporator may be

linearly scalable depending on the capacity of the apparatus.

The predetermined value/range of the process fluid flowrate of the evaporator may range from 0.10-0.30 L/min, preferably 0.15-0.25 litres/min.

The cleaning protocol may include circulating anti-fouling solution through one or more process equipment used in the method. Suitably, the cleaning protocol includes circulating anti-fouling solution through the heat exchanger until the pressure returns to the predetermined value/range.

The anti-fouling solution may be water, an acidic or a basic solution. Preferably, the solution is of food grade quality.

Where the anti-fouling solution is water, it may be maintained at a temperature ranging from 20-40°C. Suitably, the water is maintained at a temperature ranging from 30-40°C. More suitably, the water is maintained at a temperature of about 35°C.

Where the anti-fouling solution is a basic solution, it may have a pH ranging from 8-10. Suitably, the basic solution is a hydroxide solution, such as a sodium hydroxide solution. More suitably, the basic solution has a concentration ranging from 10-20% (0.25-1 M).

Where the anti-fouling solution is an acidic solution, it may have a pH ranging from 4-6. Suitably, the acidic solution may comprise an edible acid including acetic

acid, citric acid or malic acid. More suitably, the acidic solution has a concentration ranging from 5-20% (0.25-1 M).

The cleaning protocol may include activating a valve to release anti-fouling reagent from a storage tank into a heat exchanger or evaporator.

The cleaning protocol may include subjecting fluid conduits of a heat exchanger or evaporator to ultrasonication.

The cleaning protocol may include performing a rinse cycle to purge the anti-fouling reagent before terminating the cleaning protocol. The rinse cycle would purge anti-fouling reagent or waste material.

The method may include releasing process fluid from the storage tank after the rinse cycle.

The present ~~invention~~disclosure further provides an apparatus for concentrating a process fluid, including a carrier fluid, comprising:

a heat exchanger to maintain the process fluid at a predetermined temperature value/range;

an evaporator in fluid communication with the heat exchanger to receive the process fluid and evaporate the carrier fluid from the process fluid to produce a concentrate;

at least one sensor for monitoring a process variable across the heat exchanger or the evaporator to detect fouling of the heat exchanger or the evaporator;

a cleaning system to reduce fouling in the apparatus; and

a controller configured to receive signals from the sensor or a manual user input to initiate the cleaning system if the process variable deviates from a predetermined value/range.

In another aspect, there is provided an apparatus for concentrating a process fluid, including a carrier fluid, comprising:

a heat exchanger to maintain the process fluid at a predetermined temperature value/range;

an evaporator in fluid communication with the heat exchanger to receive the process fluid and evaporate the carrier fluid from the process fluid to produce a concentrate and an effluent carrier fluid;

at least one sensor for monitoring a process variable across the heat exchanger or the evaporator to detect fouling of the heat exchanger or the evaporator;

a cleaning system to reduce fouling in the apparatus;

a controller configured to receive signals from the sensor or a manual user input to initiate the cleaning system if the process variable deviates from a predetermined value/range; and

a drift chamber located downstream of the evaporator having a plurality of run-off outlets to receive at least part of the effluent carrier fluid from the evaporator prior to returning the carrier fluid to the evaporator.

The apparatus may include a condenser to condense the evaporated carrier fluid. Suitably, the condenser may be in fluid communication with the heat exchanger.

The apparatus may include a conduit for recycling part of the evaporated carrier fluid as the fluid for humidifying the mass transfer fluid.

The apparatus may include one or more pressure sensors to monitor pressure difference across the heat exchanger.

The apparatus may include a flow rate sensor to monitor mass transfer medium flow rate through the evaporator.

The apparatus may include a flow rate sensor to monitor process fluid flow rate through the evaporator.

The flowrate sensor may be a paddle flow or ultrasonic flow sensor.

The cleaning system may comprise one or more storage tanks containing anti-fouling reagent.

The controller may have a manual override to allow the cleaning protocol to be initiated manually.