Industrial Process Integration for Control and Automation: A Review

Karthikeyan.M ,
Ph.D Scholar,
Department of Electronics and Instrumentation Engineering,
Kongu Engineering College, Perundurai,
TamilNadu, India.
karthiacdc@gmail.com,

Vijayachitra.S
Professor
Department of Electronics and Instrumentation Engineering,
Kongu Engineering College, Perundurai,
TamilNadu, India.
svijayachitra@kongu.ac.in

***Abstract* - This paper gives a review for industrial process integration with Pinch Analysis and Software Tools for energy optimization. A brief case study at paper and sugar industry was also made. The case study shows that process integration plays a vital role in control and automation of industrial processes. The case study at paper industry proposes a design, to prevent the adulteration mixture in getting mixed with pulp processing sector and to regulate the chlorine supply for bleaching process. The case study at sugar industry put forward a design to automate the konti machine, based on flow, current and pH values which leads to the increase in efficiency of sugar and molasses separation process. Monitoring of pH value was implemented using LabVIEW.**

***Keywords*— Process integration, Pinch Analysis, Pulp processing, Bleaching process, Chlorine regulation, Separation process**

I. INTRODUCTION

A process denotes a series of operation on fluid or solid during which materials are placed in more useful state[1]. *Process* as used in the terms *process control* and *process industry*, refers to the methods of changing or refining raw materials to create end products. The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product.

A. Process Control

Process control refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product. Manufacturers control the production process for three reasons:

1. Reduce variability
2. Increase efficiency
3. Ensure safety

B. The Importance of Process Control

Refining, combining, handling, and otherwise manipulating fluids to profitably produce end products can be a precise, demanding, and potentially hazardous process. Small changes in a process can have a large impact on the end result. Variations in proportions, temperature, flow, turbulence, and many other factors must be carefully and consistently controlled to produce the desired end product with a minimum of raw materials and energy. Process control technology is the tool that enables manufacturers to keep their operations running within specified limits and to set more precise limits to maximize profitability, ensure quality and safety.

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II. PROCESS INTEGRATION

It is a holistic approach to process design and operation which emphasizes the unity of the process[4]. The main advantage of process integration is to consider a system as a whole in order to improve their design and/or operation, resulting in resource conservation. Process Integration techniques applied the following industrial issues:

- Energy saving and GHG emission reduction
- Debottlenecking of the critical areas in a given process
- Optimization of batch processes
- Optimization of hydrogen use
- Reactor design and operation improvements
- Minimization of water use and wastewater production
- Waste minimization
- Investment cost reduction
- Increase plant controllability and flexibility

There are two approaches to an integrated process design.

- ✓ First one is the ***Pinch concept*** for integrating energy (e.g., targeting heating and cooling utility consumptions)
- ✓ Another one is the ***Mathematical Optimization*** approach (e.g., minimizing effluent treatment flow rates in a wastewater treatment system)

III. PINCH ANALYSIS

Pinch analysis[10] is a methodology for minimizing energy consumption of chemical processes. It deals with calculation of thermodynamically feasible *energy targets* (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions.

The main objective of Pinch Analysis is to achieve financial savings in the process industries by optimizing the ways in which process utilities (particularly energy, mass, water, and hydrogen), are applied for a wide variety of purposes. The normal process is shown in Fig.1 and the process using Pinch Analysis is shown in Fig.2.

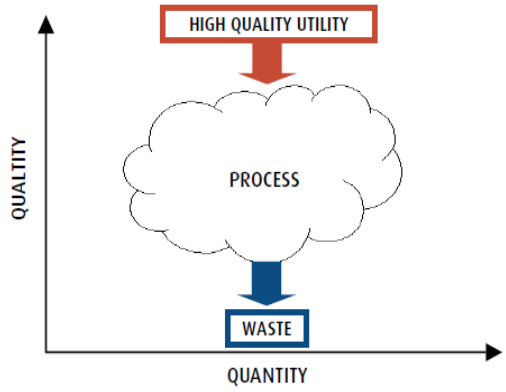

Fig.1 Normal Process

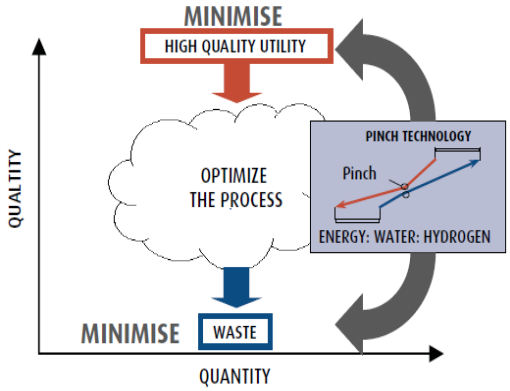

Fig.2 Process using Pinch Analysis

A. *Possible Benefits:*

- Pinch Analysis will quickly identify where energy savings are likely to be found
- Reduction of emissions
- Pinch Analysis enable the engineer with tool to find the best way to change the process

B. Pinch applications:

Pinch analysis has been successfully applied to the following process industries:

- Oil refining (crude and vacuum units, FCC etc)
- Petrochemical
- General chemical
- Food and Drink (mainly Dairy and Brewing)
- Sugar (beet and cane)
- Pulp and Paper
- Specialty chemicals
- Iron and steel

IV. ENERGY OPTIMIZATION AT INTEGRATED PULP AND PAPER MILLS

. This work deals with energy optimization in evaporator and digester of integrated pulp and paper mills[9] in India, and recommends application of 7 effects/plates evaporator in place of 5 effects/plates normally used. Steam economy resulting from this modification is definitely more than 7. Pinch technology is found suitable for optimization of controlled parameters in the digester. Using recommendations, total energy savings was observed in West Coast Paper Mill (11.74%) and Star Paper Mill (12.97%).

V. SOFTWARE TOOLS OVERVIEW

Process Network Synthesis (PNS) [7] Solutions is a software package where solving is based on P-graph approach. The P-graph framework has been introduced by Friedler et al. (1992) and further developed for systematic optimal synthesis of industrial processes. The aim of PNS is to examine the feasible structures and select the optimum. The optimal structure can be assessed in terms of cost, profit, etc. To define the optimal structure, both structural information (which and how functional units are connected) and sizing information are needed. The issues addressed by PNS Solutions are: (i) Representation of the building blocks of a process network, (ii) The solution structures of the problem, (iii) Finding the maximal superstructure, (iv) Finding the optimal structure. This is a novel tool for energy saving and pollution reduction.

Waste-to-Energy (W2E) software is a supporting tool for technological process simulation. It has been developed in Java and provides a user-friendly environment and intuitive operation. The principle of modelling and simulation is the same as in other similar systems. It creates a flowsheet, setting data and running simulation. W2E uses sequential-modular approach for computations. The main features are (i) Setting input data; (ii) Checking computed values (temperature, enthalpy, and composition); (iii) Easy extension of new blocks and streams is possible.

ProSim [8] is a leading European chemical engineering software company delivering process simulation solutions to process industries such as chemical, petrochemical, refining, oil, gas treatment, specialties chemical industries, pharmaceutical, food processing and energy industries. Its activities also comprise engineering process consulting and custom software development. ProSim solutions are used to improve process design, increase plant efficiency and reduce their impact on environment.

VI. CASE STUDY AT PAPER INDUSTRY

Paper is a major product of the forestry industry, and is used widely in our society. Paper products are used not only in their noticeable applications in the publishing industry and for writing on, but also in a variety of specialty papers, cardboards, brown papers etc. In addition, various chemicals are produced as a byproduct of the pulp and paper industry.

The paper industry uses two main raw materials for manufacturing paper – wood and recovered paper . Kaolin, starch and other products are used as supplementary materials in the paper production process. Pulpwood used for papermaking once came from whole mature trees. Today, the

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papermaker usually uses parts of the tree that are left after wood has been used for other commercial purposes.

Paper industry in India is the 15th largest paper industry in the world. It provides employment to nearly 1.5 million people and contributes Rs 25 billion to the government's kitty. The government regards the paper industry as one of the 35 high priority industries of the country. The annual global paper and paperboard production was approximately 382.0 million tones in 2006. It is expected to increase to 402.0 million tones by 2010 and 490.0 million tones by 2020. In India pulp and paper Industry is the sixth largest consumer in the industrial sector.

The paper manufacturing process is outlined below [2], [3].

1) Wood preparation:

The bark is removed from in-coming logs, and these are then chipped.

2) Cooking:

The wood chips are heated in a solution of NaOH and Na_2S in a pressure cooker, during which time a lot of the lignin (the reinforcing susbstance that make tree cells wood hard and 'woody' rather than soft like those of other plants) is removed from the wood. The pressure is then released suddenly, causing the chips to fly apart into fibres.

3) Pulp washing:

The pulp is washed with water to wash out the cooking chemicals and lignin from the fibre so that they will not interfere with later process steps.

4) Pulp screening:

A sieve is used to remove knots and clumped-together uncooked fibres from the pulp.

5) Bleaching:

This is done in two stages. Firstly the pulp is treated with NaOH in the presence of O2. The NaOH removes hydrogen ions from the lignin and then the O_2 breaks down the polymer. Then, the pulp is treated with ClO_2 then a mixture of NaOH, O_2 and peroxide and finally with ClO_2 again to remove the remaining lignin. The pulp bleaching is shown in Fig. 3.

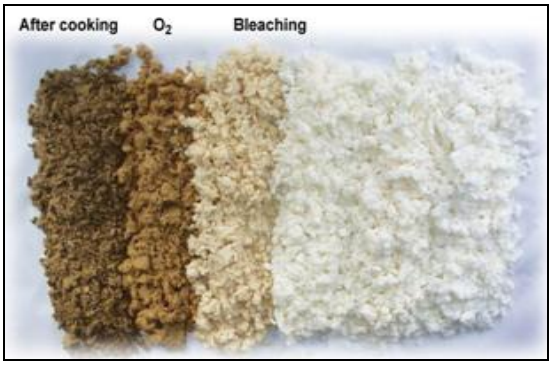

Fig. 3 Pulp bleaching

The dark colour of the paper is mainly due to residual lignin. This is removed gradually during bleaching.

6) Paper making:

The fibres are mechanincally treated to make them bond better to each other (strengthening the paper), chemicals added to provide special properties such as colour or water resistance, and then the water is squeezed out and the pulp is rolled smooth and dried. Various additional processes result in the recovery of CaO, NaOH and Na_2S, the major chemicals used in the process. Various utilities ensure that such conditions as sufficient reaction times and adequate mixing are met. On site processing removes the lignin from the liquid wastes, and solid wastes are generally taken to a landfill.

VII. PROJECT DESCRIPTION

A. Existing methodology and their problem:

Generally, in pre heater, the input fed to the system is black liquor and steam at 193^{o}c. From the outlet, the hot liquor is collected on one side and condensed water (produced due to passing of steam on outer surface of pipe**)** is collected separately. Heating action takes place in collected condensed water. After heating, this hot water is used to wash the pulp along with the chlorine supply on other side in order to get brightness for the pulp. And also the purpose of washing pulp with hot water is to remove unwanted solid waste and to maintain optimum temperature at 80-90 ^{o}c, for the pulp, to react easily with chlorine. Now, the liquor will act as fuel for cooking the bark chips. Sometimes leakage will take place due to present of holes in the pipe of pre heater and causing, leakage of liquor from the pipe which will mix with condensed water[5]. This results in adulteration. Consequently the colour and quality of the pulp will be affected. Now, the current method handles with manual mode of operation. They carry out the process by testing method where they collect some sample of the liquid for every one hour and will carry out the conductivity test on the sample liquid. Within the testing time there may be a probability of affecting the process and it may affect the brightness of the pulp. For chlorine regulation supply, current method handles with feedback controller. The feedback controller deals with manual mode of set point variation which involves chlorine regulation problem for bleaching the pulp.

B. Proposed method

In order to overcome the above problem, our methodology will supply a suitable solution to prevent the adulteration mixture in getting mixed with pulp process sector. This paper proposes a design, to separate the adulteration liquid (hot water and liquor) in one side and leaving out condensed water on another side by using two ported solenoid valve, conductivity sensor and relay coil as shown in the Fig 4.

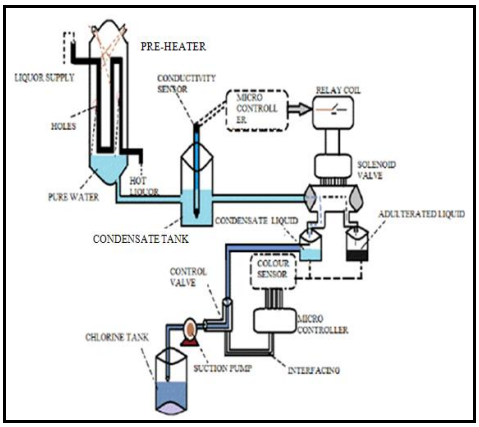

Fig. 4 Adulteration Liquid Test & Automatic Bleaching Control

We are using two solenoid valves for separation purpose, conductivity sensor for measuring conductivity of

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S.No	Liquid Name with Ratio	Conductivity range (mho)
1	Normal Water	1.26
2	Ink+water (with ratio 1:2)	0.65
3	Ink+water (with ratio 1.25:2)	0.59
4	Ink+water (with ratio 1.50:2)	0.55

the hotwater and relay coils for exciting the solenoid valve. separation process take place. The micro controller will be programmed based on conductivity of the liquid with the limit range of (0-5) for adulteration liquid and (5-10) for pure liquid Separation is done based on above methodology. If the conductivity of the liquid from condensate tank is less than 5microsimons, the relay coil-1 will excite the valve-1 and the liquid will flow through that opening. If the conductivity goes above 5 micro simons, then the relay coil-2 will excite the valve-2 and previous valve will close. In this way the based on the liquid present, the heating coil adjusts its heating capacity. From that hot liquid, the PH value is measured using and fed to the controller .Based on this value, the control valve will regulate the chlorine supply for bleaching process. The control valve will regulate the chlorine supply based on its end openings. The hardware setup is shown in the Fig. 5.

Fig. 5 Hardware setup

C. Advantages:

- Can provide the effective bleaching process.
- Easy method of separation of liquid based on conductivity
- Automatic chlorine regulation will enhance the pulp brightness and secure the pulp quality.

VIII. EXPERIMENTAL RESULTS AND DISCUSSIONS

For experimental work, normal water is considered as hot water, which is used for pulp washing and black ink for black liquor. The Table I and Fig.6 shows the conductivity range for various liquids. The table also infers that, the conductivity is high for normal water and when it is mixed with ink, the conductivity decreases.

TABLE I
Various liquids and their conductivity range

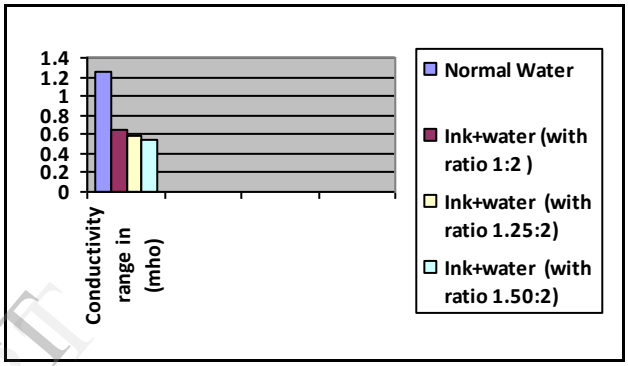

Fig. 6 Various liquids and their conductivity range

IX. CASE STUDY AT SUGAR INDUSTRY

Sugar is a material used worldwide as a sweetening agent. The main source of sugar is sugar-cane from which it is manufactured industrially. Sugar is obtained from sugar beet, which is grown in temperate climates. The primary components of sugar are (i) Water (ii) Soluble solids (iii) Fibre. Sugar is the main constituent of the soluble solids of sugar-cane juice.

Indian sugar industry, second largest agro-based processing industry after the cotton textiles industry in country, has a lion's share in accelerating industrialization process and bringing socio-economic changes in under developed rural areas. India is the fourth major sugar producing country in the world, the first three being Russia, Brazil and Cuba. Sugar industry covers around 7.5% of total rural population and provides employment to 5 lakh rural people. About 4.5 crore farmers are engaged in sugarcane cultivation in India. The annual turnover of industry is tot the tune of Rs. 25,000 crores. The sugar manufacturing process is outlined below as shown in theFig.7.

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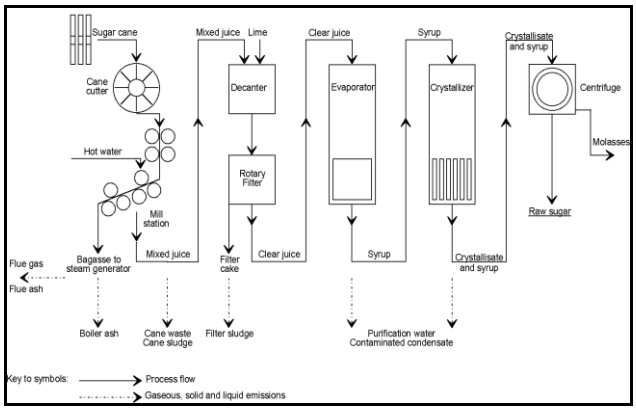

Fig.7 Sugar manufacturing process

1) Growing the Cane:

Sugar cane is a sub-tropical and tropical crop that prefers lots of sun and lots of water - provided that its roots are not waterlogged. It typically takes about 12 months to reach maturity although the time varies widely around the world from as short as six months in Louisiana to 24 months in some places. Where it differs from many crops is that it re-grows from the roots so the plant lasts many cycles [or 'ratoons', a word derived from the Spanish to sprout] before it is worn out.

2) Harvesting:

Sugar cane is harvested by chopping down the stems but leaving the roots so that it re-grows in time for the next crop. Harvest times tend to be during the dry season and the length of the harvest ranges from as little as 2 ½ months up to 11 months. The cane is taken to the factory: often by truck or rail wagon.

3) *Extraction:*

The first stage of processing is the extraction of the cane juice. In many factories the cane is crushed in a series of large roller mills: similar to a mangle [wringer] which was used to squeeze the water out of clean washing a century ago. The sweet juice comes gushing out and the cane fibre is carried away for use in the boilers. In other factories a diffuser is used as is described for beet sugar manufacture. Either way the juice is pretty dirty: the soil from the fields, some small fibres and the green extracts from the plant are all mixed in with the sugar.

4) Evaporation

The factory can clean up the juice quite easily with slaked lime (a relative of chalk) which settles out a lot of the dirt so that it can be sent back to the fields. Once this is done, the juice is thickened up into a syrup by boiling off the water using steam in a process called evaporation. Sometimes the syrup is cleaned up again but more often it just goes on to the crystal-making step without any more cleaning. The evaporation is undertaken in order to improve the energy efficiency of the factory.

5) Boiling:

The syrup is placed into a very large pan for boiling, the last stage. In the pan even more water is boiled off until conditions are right for sugar crystals to grow. You may have done something like this at school but probably not with sugar because it is difficult to get the crystals to grow well. In the factory the workers usually have to throw in some sugar dust to initiate crystal formation. Once the crystals have grown the resulting mixture of crystals and mother liquor is spun in centrifuges to separate the two, rather like washing is spin dried. The crystals are then given a final dry with hot air before being stored ready for despatch.

6) Storage:

The final raw sugar forms a sticky brown mountain in the store and looks rather like the soft brown sugar found in domestic kitchens. It could be used like that but usually it gets dirty in storage and has a distinctive taste which most people don't want. That is why it is refined when it gets to the country where it will be used. Additionally, because one cannot get all the sugar out of the juice, there is a sweet by-product made: molasses. This is usually turned into cattle food or is sent to a distillery where alcohol is made.

7) Power:

The fibre obtained from crushing the sugar cane is called "bagasse" in the industry. The factory needs electricity and steam to run, both of which are generated using this fibre.

The bagasse is burnt in large furnaces where a lot of heat is given out which can be used in turn to boil water and make high pressure steam. The steam is then used to drive a turbine in order to make electricity and create low pressure steam for the sugar making process. This is the same process that makes most of our electricity but there are several important differences.

When a large power station produces electricity it burns a fossil fuel [once used, a fuel that cannot be replaced] which contaminates the atmosphere and the station has to dump a lot of low grade heat. All this contributes to global warming. In the cane sugar factory the bagasse fuel is renewable and the gases it produces, essentially CO_2, are more than used up by the new cane growing. Add to that the factory use of low grade heat [a system called co-generation] and one can see that a well run cane sugar estate is environmentally friendly.

X. PROJECT DESCRIPTION

A. Existing methodology and their problem:

In most of the sugar industries, conventional method of sugar manufacturing is followed. Konti machine is the centrifugal machine which is used in the sugar and molasses separation process as shown in the Fig.8.

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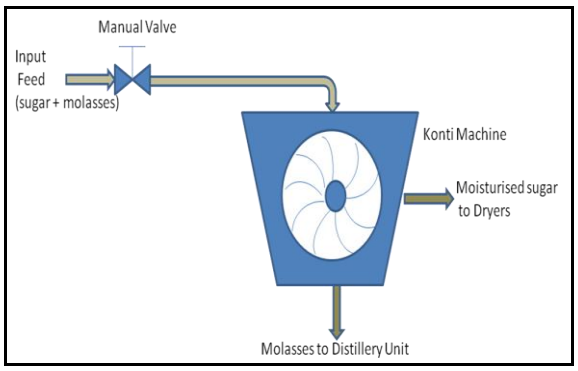

Fig.8 Konti machine used in the sugar and molasses separation process

The sugar and molasses combined called as massecuite is sent as input feed to konti machine. when the massecuite is operated at a high temperature in konti machine[6], viscous liquid is converted in to powdered form. Then the powdered material is again mixed with water and taken to boiler. In this way, molasses in sugar is separated to the maximum. When the current consumption of konti machine is more than certain limit, the machine is needed to be shut down manually. It leads to the necessity of availability of workers always, reduction of power factor, motor windings getting damaged, operating speed is affected leading to slow production process

B. Proposed method

In order to overcome the above problem, our methodology will supply a suitable solution. This paper proposes a design, to separate the sugar and molasses separation process efficiently. In our design, konti machine is automated based on flow, current and pH values as shown in the Fig.9.

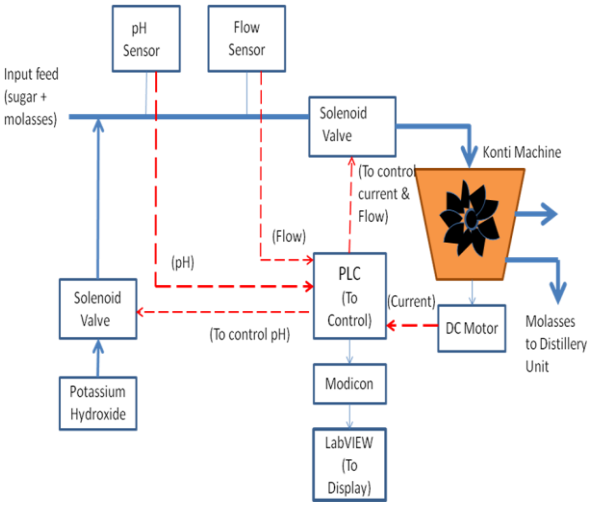

Fig.9 Konti machine automation

The input flow value is measured with flow sensor and given to PLC, the current is being measured with current transformer with voltage level control circuit and taken to PLC. From PLC, based on those values, the output is taken to the Solenoid Valve. In industry, pH value is maintained around 7-8.9. The safer value is within 7-7.6. So in order to maintain the pH value,feedback loop is formed. Epoxy electrode gel filled pH sensor is taken for its measurement and taken to PLC. The output is given to another solenoid valve. LabVIEW is used for display purpose. PLC and LabVIEW is interfaced using Modicon Modbus which is a serial communication protocol.

C. Advantages:

- Prevention of Konti machine overloading, reduction of power factor, motor windings getting damaged.
- Drive durability is increased , as a result total production is increased
- Operating speed is not affected
- pH control is obtained

XI. EXPERIMENTAL RESULTS AND DISCUSSIONS

For Experimental work, we used normal water instead of massecuite. Fig. 10 and Fig. 11 shows pH value measurement using NI ELVIS and LabVIEW.

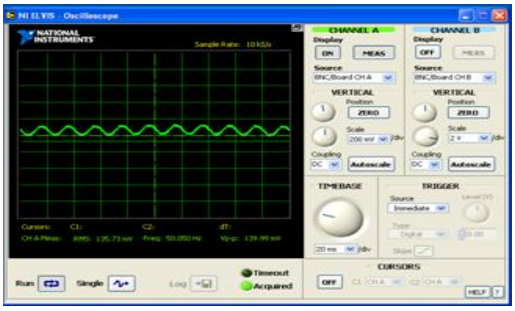

Fig.10 Before pH value measurement using NI ELVIS and LabVIEW.

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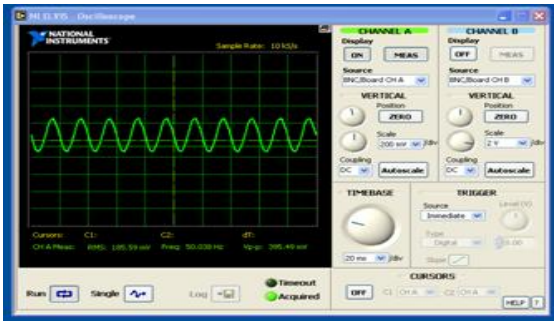

Fig 11 After pH value measurement using NI ELVIS and LabVIEW.

XI CONCLUSION

Thus this paper gives a review for industrial process integration with Pinch Analysis and Software Tools for energy optimization and a brief case study at paper and sugar industry. The case study suggests that process integration plays a vital role in control and automation of industrial processes.

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