Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 5; April-June, 2015 pp. 386-390

http://www.krishisanskriti.org/jmsme.html

IN-PROCESS TEMPERATURE CONTROL SYSTEM FOR ELECTROWINNING PROCESS USING THERMO ELECTRIC COOLER

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Abstract—*A thriving growth of production in the field of process industries is in a continuously increasing need of smart and automatic control systems. Temperature control is very important aspect in process industries and a variation in the same will affect the process outcome. In this research work an attempt is made to control and monitor the temperature in the electro winning process where zinc is extracted from the Zinc sulfate solution. The microcontroller based system includes temperature sensors, specifically LM35 located in each electrowinning process units to produce electrical signals proportional to the process temperature. The controller actuates the relay switch of thermo electric cooler (TEC) to take appropriate control action based on sensed temperature signals. Results obtained during the test run is the optimum value for maximum zinc extraction is 40^0c. A prototype model was developed in the laboratory and it is efficiently maintaining the optimum temperature.*

Keywords: *Electrowinning process temperature; Temperature sensor LM35; Controller ATmega16®; Control action TEC; Temperature control system.*

1. INTRODUCTION

Temperature monitoring and control plays an important role in the continuous process industries like chemical industries. This project aims at monitoring the temperature of individual electrolytic cells during the zinc extraction process, in order to control the current being used up which is unwanted in the plant and also increase the efficiency of the production process. LM35 is used for sensing cell temperature and all the sensor inputs are linked up to ATmega16 (controller). The control action will be taken by the controller by referring the set point value. The whole system is connected to graphical interface software for monitoring and controlling purpose. The communication channel used is USB module.

The developed prototype of Cell house will consist of four no. of electrolytic cells. Each cell consists of 4 anodes and 4 cathodes. Zinc will be extracted from this cell house as a result of the electro-winning process. For the extraction process a temperature range of 30ºC - 40ºC is required and has to be maintained. The increase in temperature may cause increase in the electric current used. Most often the temperature rises to very high range so that enormous current will be used up. The enormous current can destroy the electrodes used for the process and also results in loss of electrical energy. In order to avoid those difficulties it is necessary to control the temperature in the process. For this we can use temperature sensor like LM35 and Lab VIEW system to measure, monitor and control the temperature and if the temperature exceeds the limit then LCD display and buzzer will be activated. Then necessary steps will be taken to lower the temperature and hence the electrical energy can be controlled and saved.

Zinc is a chemical element with symbol Zn and atomic number 30. Around 80% of zinc mines are from underground of earth, 8% are of the open pit type and the remaining part is a combination of both. Over 95% of the world's zinc is produced from zinc blend (ZnS). Apart from zinc the concentrate contains some 25-30% or more sulphur as well as different amounts of iron, lead and silver and other minerals. Pure zinc is produced from these concentrates by different hydrometallurgical process. The process of extraction of zinc from ZnS contains a number of stages including primary and secondary zinc processing.

ROASTING : Zinc is present as Zinc Sulphide (ZnS). by using either hydrometallurgical or pyrometallurgical techniques, sulphur in the concentrate must be removed. This is done by roasting or sintering.

$$2ZnS + 3O_2 \longrightarrow 2ZnO_2 + Heat$$

LEACHING : In a leaching stage the zinc oxide is separated from the other calcines. Sulphuric acid is used to do this. Leaching is easier to perform and much less harmful, because no gaseous pollution occurs.

$$ZnO + H_2SO_4 \longrightarrow ZnSO_4 + H_2O$$

ELECTROLYSIS : The obtained purified solution passes an electrolytic process where the purified solution is electrolyzed between zinc anodes and graphite cathodes. An electrical current is circulated through the electrolyte by applying an electrical difference of 3.3-3.5 volts between the anode and cathode causing the zinc to deposit on the graphite cathodes in high purity [1]. A good comparison between uni-polar and bipolar electro-winning cell modeling is made in copper production electro-winning process. Serially connected bipolar electrodes are not wire connected but are just immersed in electrolyte hence uses much lower DC current comparatively [2]. Advances and trends in primary and small secondary batteries with Zinc anodes and manganese dioxide are air cathodes. The study tells Zinc cells can produce more service than lithium cells [3]. A verity of temperature sensors like thermostat, thermistor, RTD, thermocouple, LM35 etc are available. Lm35 has several advantages over the other temperature sensors. A remote monitoring system for temperature, voltage, current and power measurements uses three sensors, Voltage sensor, Current sensor and temperature sensor. LM35 is the temperature sensor used here because of the advantage of delivering tension as linear function of the temperature input [4]. Heat exchange due to air flow is measured by a thermocouple and an LM35. Hence constant temperature shows a variation and respective voltage can be measured. Thermocouple has high response time than LM35. Due to inherent character of ADC thermocouple output cannot be digitized [5]. Energy Saving by Automatic Control of Power in Simple Home Appliances uses different sensors and the sensor used for temperature measurement is LM35 [6]. The application of soil temperature measurement by LM35 temperature sensors, here the theoretical equation between sensor output voltage and Celsius temperature also carried out [7]. Controller is the heart of any embedded system. Research on the elevator door control system based on the image processing technology. Here image acquisition chip of elevator used is 0V7620 and the image is transmitted to the main controller ATmega32 and the control action is done [8]. Fabrication of MEMS based temperature sensor, controlling and monitoring is done by Lab-VIEW. From sensor to ADC and then to PC via wireless data acquisition device [9].

2. METHODOLOGY

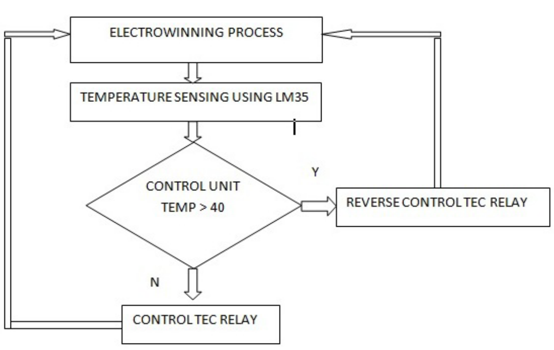

Fig. 1: Step by step procedure

The step by step procedure of the project is shown in fig. 1. Since the objective of the project is to monitor and control the tank temperature of zinc electro-winning process, LM35 is used as the sensor. A sensor is a device which detects or measures a physical property and records, indicates, or otherwise responds to it. The LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature (in ^{o}C). The output voltage which is proportional to the change in Celsius temperature is given to the controller. After crosschecking, the controller will send the data to the computer and at the same time it activates the relay circuits for the proper control action. The control action will be interchanging the poles of relays, so that actuator will heats or cools the electrolyte with the help of a driver mechanism. TEC (Thermo Electric Cooler) is used as an actuator because, It can be used either for heating or for cooling, although practically the main application is cooling. Again the same process will be continuing till the zinc get extracted completely. Hence this forms a control loop. With the help of proper interfacing of graphical software like LabVIEW®, temperature monitoring also can be done. A keypad and a LCD display is given for make it more user friendly. Full setup is properly power supplied.

3. EXPERIMENTAL SETUP

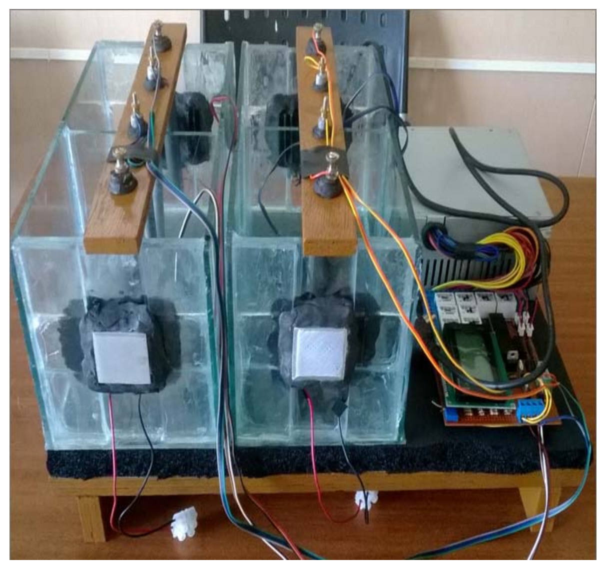

Fig. 2: Experimental setup

Fig. 2 shows an overall model of the setup. The setup consists of 2 tanks with 2 compartments each. Two electrodes per compartment were used for the process. The cathode electrode was a graphite electrode and the anode was a zinc electrode. The components used for the development of mechanical hardware parts and its design specifications are listed in table 1. An electric potential of 3.3v was maintained throughout the process. Electro winning process requires a closed loop temperature control system. A temperature sensor is used to monitor the temperature within each compartment. The sensors would generate a voltage proportional to the temperature. The voltage would be sampled by an analog to digital converter which is built into an MCU for the operation of a closed temperature control loop. The temperature would need to be maintained at 40^0C. A thermo electric cooler which is a solid state heating and cooling unit was used to maintain the temperature of each compartment. The control unit used combinations of relays and transistors to control the TEC. 8 bit pulse width modulation (PWM) was used to control the TEC voltage.

The system needed 3 different voltages for its operation 3.3v was used for the electrodes, 5v was used for the electronics and 12V was used for the TEC to operate. Since the system required close to 300W at maximum performance a switching mode power supply was used. The control unit used two micro controllers to control four compartments both the controllers were interconnected there by setting a master slave arrangement. The control unit features a text based LCD with an alpha numeric keypad for user interaction the system can also connect to the USB port of a PC by simulating a comport and can achieve a maximum transfer speed of 192000 bits per second.

A hyper terminal may be used to interact with the system. However to ensure a user friendly experience a graphical user interface would be required. LABVIEW® would be used to provide a virtual instrument panel there by allowing a user to monitor and control the process with ease.

Table 1: Design specification of process setup

SL. NO	COMPONENTS	DIAMENTION (cm)	NO
1	Basement	47 X 30 X 4.6	1
2	Glass beaker	14.3 X 14.3 X 16	4
3	Heat sink (big)	10 X 6.5 X 1.8	4
4	Heat sink (small)	6.5 X 4.5 X 1.8	4
5	TEC hole	4.4 X 4.9	4
6	Zinc electrode	16 X 1 (dia)	4
7	Graphite electrode	15 X 2 (dia)	4
8	Electrode holder	33 X 3.7 X 1.1	2
9	Fan	8 X 8 X 2.5	4
10	Billet	4 X 4 X 1.1	4
11	M-Seal	-	-

4. CONTROLLER MODULE OF THE SYSTEM

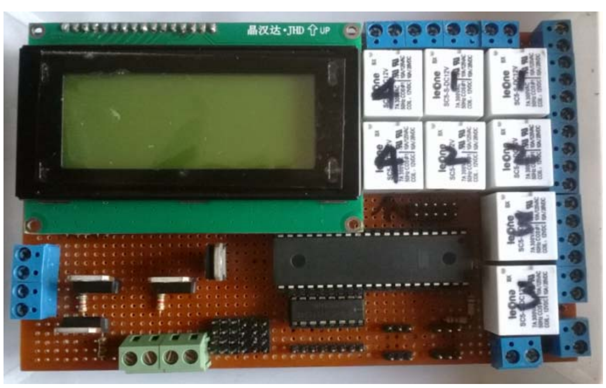

Fig. 3: Controller module

Fig. 3. shows a fabricated circuit of the Micro controller unit. This unit consists of an LCD display which is shown on the top left corner. Two microcontroller chip which in this case is ATmega16® are used and one is below the LCD unit and another is seen which is followed at the bottom by ULN 2003 which will conduct the communications by a keypad. There are number of relays that are seen in white color and are also numbered according to the TEC they are connected. The transistors that are seen in the circuit are the amplifier modules. The power connectors which can be seen in the corners of the board are from where there will be inputs and outputs can be controlled. There are also some pins provided to connect the TEC outputs, power inputs and keypad. The components used for the development of electronics hardware parts and its design specifications are listed in table 2.

Table 2: Design specification of control module

SL. NO	COMPONENTS	SPECIFICATION	No
1	Dotted PCB board	140 X 90 (mm)	1
2	ATmega16® (base)	40 Pin – DIP	2
3	LCD	16 X 4 (mm)	1
4	ULN 2003 (base)	5X5X5 (cm)	2
5	USB module	TTL 4 pin connector	1
6	Keypad	70 X 77 X 1 (mm)	1
7	TEC	40 X 40 X 3.8 (mm)	4
8	LM35	10mv/ °C	4
9	Mosfet	IRFZ533 with heat sink	4
10	Resistors	15, 5.2, 8.2(k), 68, 47(ohm)	11, 5, 1, 5, 5
11	Berg strips	-	M - 3, F - 1
12	Pot	10k	1
13	2 pin connectors	-	18
14	Relay	12v	8
15	SMBS power supply	450 watt, 24 pin	1

5. CIRCUIT DIAGRAM

In order to develop the whole control unit the above mentioned design aspects are followed and the developed system is revealed with the help of circuit diagrams fig. 4 and fig. 5. Total of two ATmega16® is used in order to control the whole process. Signals from temperature sensor LM35 and TEC voltages are given to port A of master microcontroller. TEC voltage connections are given with the help of mosfet. Port B, port C and port D of master microcontroller is connected to data, LCD and TEC mode respectively. Inputs from the keypad is given to the slave microcontroller through ULN 2003 to port C. Port A, port B and port D of slave microcontroller is connected to electrode voltage, data and TEC power respectively.

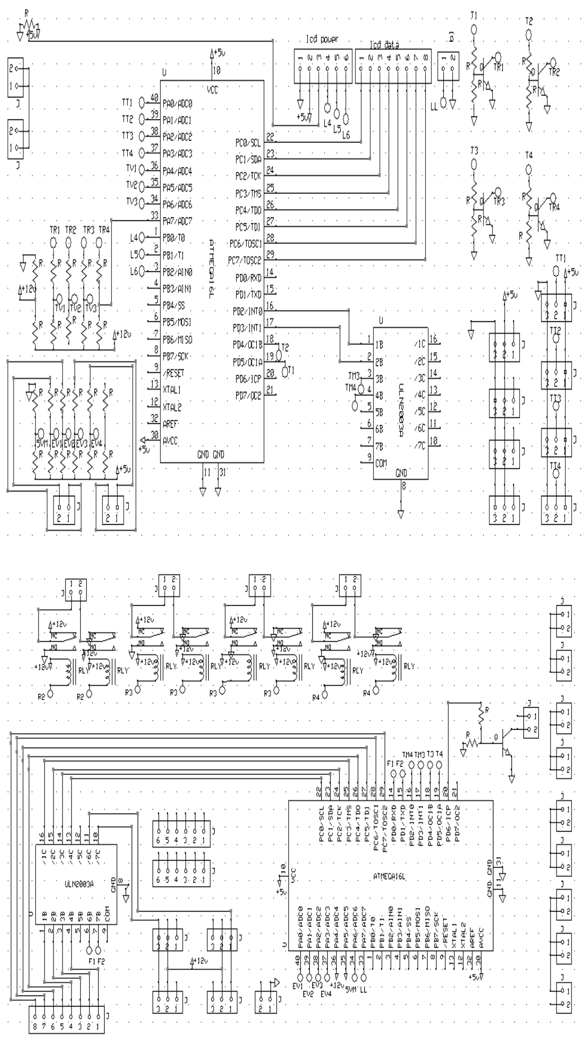

Fig. 5: Controller module part 2

The required power supply 12v, 5v and 3.3v respectively for each components are supplied by SMBS power supply module whose wires are following PSU colour code. LCD pins and MCU pins are directly connected for the data transmission. Control command from microcontroller to the TEC is given to the relays. Relays will be changing its polarity connections accordingly.

6. RESULTS AND DISCUSSION

The research has given a good set if results that can demonstrate us about how important is controlling the temperature in the electro wining process is. The following table 3. is a representation of the voltage temperature and time values taken during the test run. As it can be seen from the table that there were 16 values temperature at different time intervals which is representing a study increase of temperature.

Table 3: Temperature verses time at constant voltage for zinc deposition

VOLTAGE (volt)	TEMPERATURE (degree Celsius)	TIME (cumulative min)
0	27	0
3	29	6
3	30	10
3	31	12
3	32	13
3	33	14
3	34	15
3	35	16
3	36	17
3	37	18
3	38	19
3	39	20
3	40	21
3	41	22
3	42	23
3	43	24

Table 4. Readings during electrowinning process at different temperature

TEMPERATURE (degree Celsius)	TIME (minute)	DEPOSITION (gram)
27	60	5.2
30	60	6.4
35	45	8.2
40	20	9.3
45	20	9.3
50	20	9.2
55	20	9
60	20	8.1
65	20	7.5
70	20	6.4

Table 4. and fig. 6. explains that, as the temperature keeps increasing with respect to that of the time the level of zinc deposition will also increase to an extent. But as the temperature keeps increasing even after a saturation level where the zinc deposition is maximum the deposition level will again keep going down gradually and more current will be drawn.

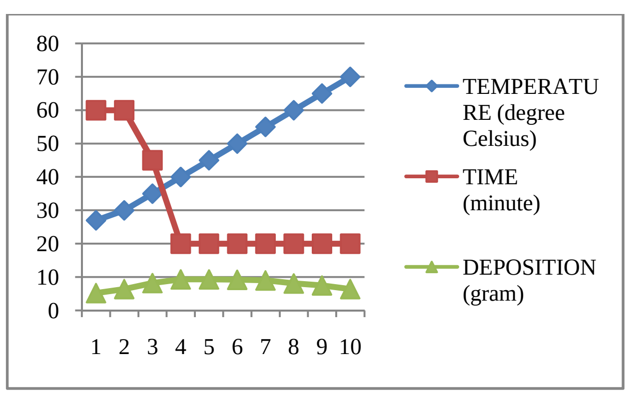

Fig. 6: Temperature verses time verses deposition graph

Fig. 7: Extracted Zinc

The above fig. 7. shows a proper deposition of zinc when a temperature which is optimum is maintained. In the table below there is also a representation of the deposition levels of zinc at various times and temperatures.

7. CONCLUSION

This research was successful in making a control unit that was well tested and is capable of monitoring and controlling the electro wining process. This unit can act as a good tool for industrial control systems which will be involved in chemical process control and many more areas. The levels of temperature and time will be varying according to the chemical used and the product to be produced. With proper design and study of characteristics of a chemical process this unit can be designed to control and monitor not only the Zinc production process, but can also be used for a wide range of chemical processes. With a careful and precise level of circuit fabrication and programming and calibrating the sensors this module can be used for a precision control of the electro wining process.

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