Real Time Fault Diagnosis In Continuous Stirred Tank Reactor (CSTR)

S.Vijayachitra, B.Vinosha

Abstract: In many of the industrial applications including chemical processing, pharmaceutical processing and tertiary water treatment processing and etc., Continuous Stirred Tank Reactor (CSTR) plays a major role. With continuous flow of reactants and products, the CSTR can able to run at steady state and from which the feed input is assumed to have a uniform composition throughout the reactor operation and also the exit stream has also maintained the same composition as in the tank. When there is any change in the input/output ingredients in terms of flow, level, temperature or composition, it will be reflected as a fault by means of sensor fault, process fault and actuator fault. Hence for having perfect operation, it is proposed to do real time fault diagnosis in the CSTR Skid. By varying the flow rate of inlet and outlet water to and from the CSTR in steps of 25%, 50%, 75% and 100%, the performance were analyzed and their appropriate faults were diagnosed.

Index Terms: Continuous Stirred Tank Reactor, Fault s, Diagnosis, Sensor fault, actuator fault, coolant flow, hot water flow

1. INTRODUCTION

Due to various advancements and technological developments, there is a possibility in increasing the complexity of the system. Hence, for the safe operation of the system, proper monitoring of the process and fault diagnosis are essential. In connection with the necessity of high performance as well as reliability and safety of the system under dynamical conditions and also towards the process automation, it is essential to consider fault detection and diagnosis as an important strategy which will further fulfill the economical demand. In general, any fault can be considered as an unexpected change of the process functioning due to the failure in any of the physical components present in the system. It may be further related the failure in the sensors or actuators or due to abnormal changes in process conditions. If it is possible to get the reason for malfunctioning of the system, then it is possible to rectify the faults to ensure the process safety. Fault diagnosis is carried out by identifying the deviation from any normal or desired behavior of the system. Its primary objective is to detect the origin of the failure or unexpected event. A Continuous Stirred Tank Reactor (CSTR) is most commonly preferred in many industrial processes which involve chemical reaction with the provision of constant stirring for the effectiveness of the process. In real time operation of the CSTR, the possible faults encountered are due to the change in the input/output ingredients in terms of flow, level, temperature or composition which will be reflected as a fault by means of sensor fault, process fault and actuator fault. By observing the behavioral analysis of the continuous stirred tank reactor, it is intended to identify the normal or abnormal functioning of the system which will further lead to detect the origin of the faults to be rectified [2].

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2 CONTINUOUS STIRRED TANK REACTOR

A Continuous Stirred Tank Reactor (CSTR) is the one employed in many of the chemical processes and from which continuous supply of ingredients entering into the reaction vessel. With the continuous stirring operation and the appropriate chemical reaction, there will be withdrawal of products out from the reactor [1]. The schematic diagram of a CSTR is depicted in Fig-1.

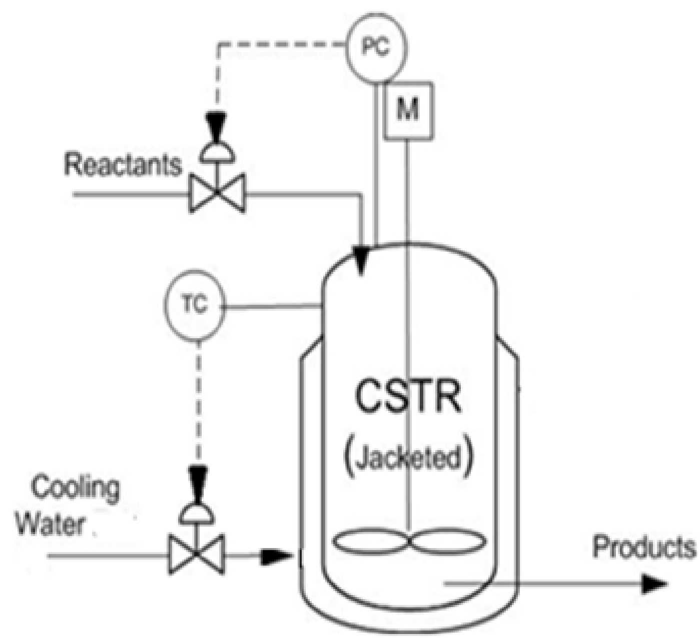

Fig-1 *Schematic diagram of CSTR*

The present CSTR skid, shown in Figure-2, used for the present study is facilitated with an interface to the system which further enables complete data logging for operator's preference. Specifically, CSTR is non linear in nature due to its principle of reaction/operation and it can be operated over wide range. Even though it can have chemical reactions of exothermic or endothermic type, it is preferably operated at steady state condition. In CSTR, the most common variables to be considered as part of control are temperature of hot water flow, coolant temperature, coolant flow and concentration of the ingredients.

Fig- 2 *Continuous Stirred Tank Reactor Skid*

The components involved in the CSTR Skid are illustrated in the following Fig-3.

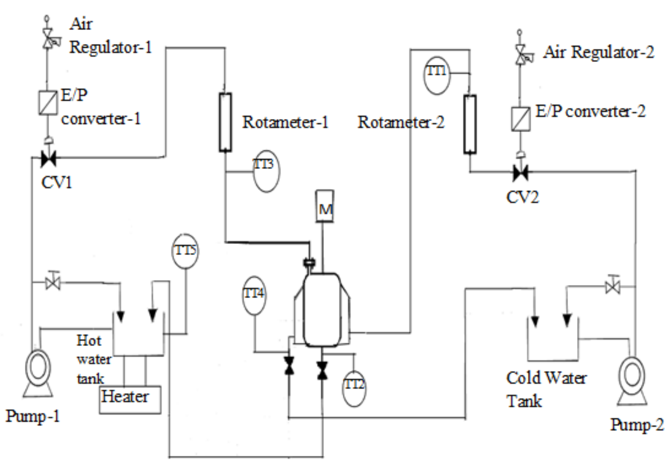

Fig- 3 *Detailed representation of CSTR Skid*

3 FAULT DIAGNOSIS

Generally speaking, the purpose of having fault diagnosis is to trace various faults by means of its different symptoms and to analyze the causes and solutions to overcome the faults [3]. A sensor is an element in order to detect changes in the physical quantity being measured and the corresponding output is to be obtained. It is called as a transducer if it is provided with suitable signal conditioning circuit like Wheatstone bridge circuit. The sensor considered in this proposed work is RTD-Temperature sensor. Based on the output signal received from the controller involved in the process, the role of an actuator is to allow the manipulated variable in order to maintain the controlled variable at a constant [4]. The proper operation of CSTR skid is dependent on the proper functioning of sensors such as temperature sensor (RTD) and flow sensor (Rotameter) and the actuator such as control valve. Hence it is essential to monitor the effective functioning of both sensors and actuators for diagnosing the faults possibly encountered from them [5].

4 FAULT DIAGNOSIS CARRIED OUT IN CSTR

4.1 Sensor Fault

In order to control the CSTR temperature, hot water is allowed to enter into the CSTR tank and its instantaneous temperature is to be measured by RTD. If there is any fault in terms of opening /closing of hot water flow by rotameter, the temperature may not be the desired one. Here Heater at hot water outlet is made ON and OFF to check its effectiveness in temperature control. When the heater is ON, the temperature of outlet stream is increasing rapidly with respect to varying time. Similarly when the heater is OFF, the temperature of outlet stream is merely equivalent to the inlet temperature. Table-1 shows the inlet and outlet temperature values of Hot Water (HW) with respect to ON/OFF condition of heater.

Table 1: *HW Temperature with respect to Heater ON/OFF*

TIME (MIN)	HEATER ON		HEATER OFF	
	INLET TEMP (°C)	OUTLET TEMP (°C)	INLET TEMP (°C)	OUTLET TEMP (°C)
5	30	30	30	30
10	32	32	32	32.5
15	34	38	34	34
20	36	44	35	35.4
25	40	46	36	36.1
30	43	50	37	37
35	44	52	39	39.1
40	46	54	40	40
45	53	58	41	41
50	60	61	41	41.5

Figure-4 shows the graphical representation of response of HW temperature with ON/OFF condition of heater.

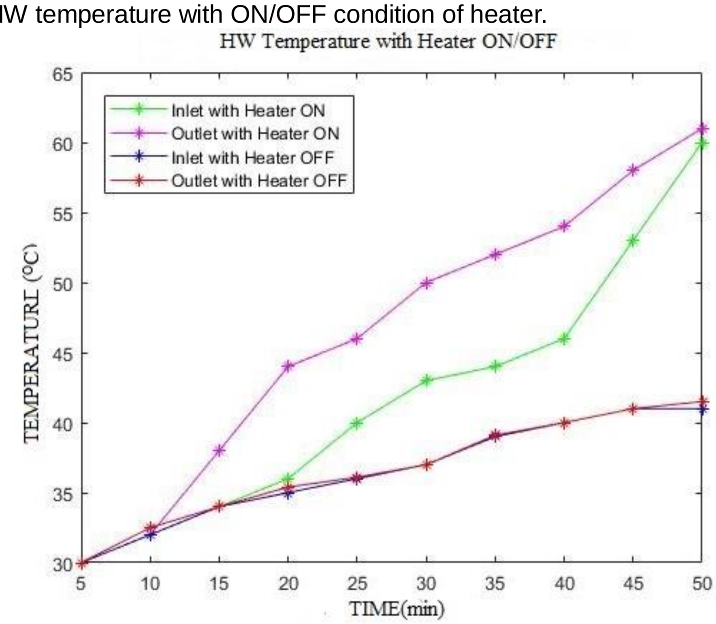

Fig-4: *HW temperature with Heater ON/OFF*

From the above Fig-4, it is inferred that when the heater is ON, the temperature of the inlet water gets increased based on the percentage of opening of actuator and it is measured at the outlet side. When the heater if OFF, the temperature values at both inlet and outlet side are the same and found no definite increase in the outlet temperature.

Condition-1:

The HW roatameter is opening in terms of 25%,50%, 75% and 100%, and the corresponding outlet temperatures are observed and tabulated in Table-2.

***Table-2**: HW Rotameter opening and outlet temperature variation*

TIME(MIN)	HW ROTAMETER OPENING	
	25%	100%
	OUTLET TEMP (°C)	OUTLET TEMP (°C)
5	30	30
10	31	34
15	32	40
20	34	47
25	35	55
30	38	70
35	39	75
40	42	78
45	47	78
50	48	78

Fig-5 shows the graphical representation of response of outlet temperature with respect to 25% and 100% opening of HW flow rate. The healthiness of the rotameter and RTD are verified.

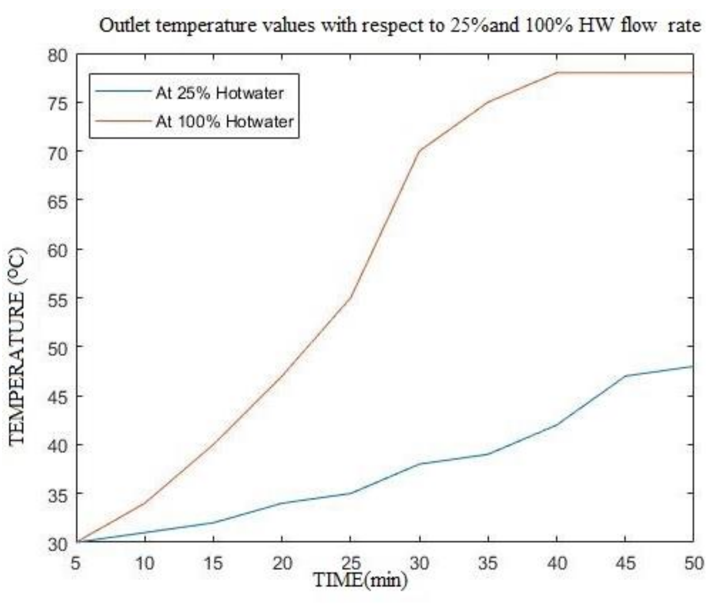

***Fig-5**: Outlet temperature values with respect to 25% and 100 % HW flow rate.*

Condition-2:

Next, by keeping the manipulated variable (coolant flow) from CW rotameter in terms of 25%, 50%, 75% and 100%, and HW temperature values are observed in terms of 25%, 50%, 75% and 100%. They are tabulated in Table-3 and Table-4.

***Table-3:** Temperature variation with respect to HW flow rate in terms of 25%, 50%, 75% and 100% and 25% CW flow rate*

COOLANT FLOW RATE 25%				
TIME(MIN)	HW TEMPERATURE (°C)			
	HW FLOW RATE			
	25%	50%	75%	100%
5	30	32	38	40
10	31	34	43	43
15	32	36.5	47	48
……				
40	36.5	46	62	70
45	37.5	48	65	75
50	38	50	68	80

***Table-4:** Temperature variation with respect to HW flow rate in terms of 25%, 50%, 75% and 100% and 100% CW flow rate*

COOLANT FLOW RATE 100%				
TIME(MIN)	HW TEMPERATURE (°C)			
	HW FLOW RATE			
	25%	50%	75%	100%
5	30	34	35	33.1
10	31	35	39	34
15	31.5	37	40	35
……				
40	33	47	51	39
45	33.1	49	52	40

Fig-6 and Fig-7 show the graphical representation of response of hot temperature with respect to 25% and 100% opening of HW flow rate and coolant flow rate of 25% and 100% respectively and from which the healthiness of the actuator is verified.

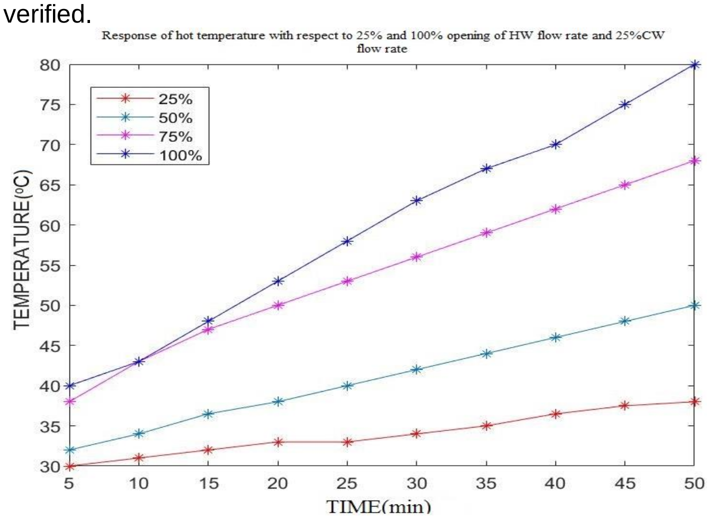

***Fig-6** Response of hot temperature with respect to 25% and 100% opening of HW flow rate and 25%CW flow rate*

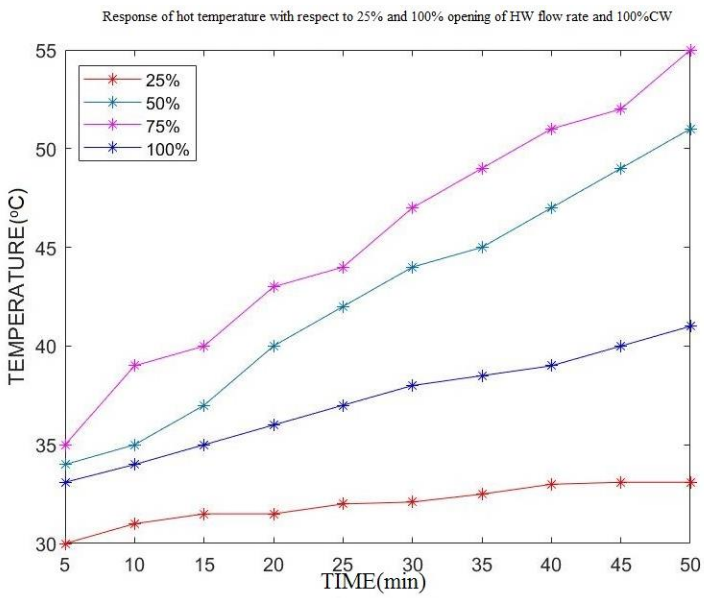

Fig-7 *Response of hot temperature with respect to 25% and 100% opening of HW flow rate and 100%CW flow rate*

From the above Fig-6 and Fig-7, it is observed the healthiness of the actuator based on the coolant flow rate as manipulated variable and by varying the coolant flow rate as well as allowing the hot water flow rate in steps of 25% and 100% respectively. If any deviation in the temperature values, it will be inferred that the fault lies with the actuator.

4 CONCLUSION

Due to the role of Continuous Stirred Tank Reactor in many industrial applications as an essential component, it is important to ensure the normal behavior of the CSTR. If there is any abnormal condition in terms of the functioning of sensors or actuators, it further leads to erroneous output in CSTR which will further affect the accuracy of the CSTR. In the proposed work, possible faults such as sensor fault and actuator fault are considered and verified their response with respect to various conditions.

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