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Smart Reactor Production Monitoring System-an Industry 4.0 Application in the Chemical Industry

Adem Kayar[(1)] Fatih Öztürk[(2)]
[(1)]Istanbul Ticaret University, Turkey
[(2)]Istanbul Medeniyet University, Turkey

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Abstract: Decrease in costs. More production flexibility. More efficient processes. These are one of the common demands of manufacturing enterprises in almost every sector. In this marketplace where there is very serious competition, the most important factor in the chemical industry is competitiveness as in every sector. The best way to take advantage of competitive advantages can be with integrated and innovative electrification, automation and digitalization solutions. Completing the digital transformation includes many disciplines, from engineering and design to automation, information technology and lifecycle management. Adopting digitalization lies in the merging of different expert knowledge, working in many different disciplines that are complex, able to offer the best solution. This strategy is also the motivation behind the strategic cooperation initiated by the German government in 2011 to promote Industry 4.0. In this article, in a chemical factory that produces paint, the project implementation of industrial automation and control systems and the details of the collection, recording, monitoring and reporting of the requested information in accordance with the Industry 4.0 concept of this application are explained. The article explains in detail how a real Industry 4.0 software application is applied in the chemical industry producing paint and reveals the benefits of Industry 4.0 in process automation. At the same time, this project, which is described in this article and implemented in a real paint production factory, will give new ideas to the industrial enterprises that are trying to realize the fourth industrial revolution and digitalization which has been on the agenda recently.

Keywords: Chemical Process, Industrial Automation and Control Systems, Industry 4.0, Smart Manufacturing, Production Systems

1. Introduction

Companies manufacturing all over the world are faced with very serious competition conditions in the globalizing world economy. In order to be more advantageous than the companies they compete with, they have to provide reduction in production costs, more production flexibility and more efficient processes (Öztürk, 2014). These are one of the common demands of manufacturing enterprises in almost every sector (Öztürk, 2015).

In this highly competitive market environment, as in every sector, one of the most important factors in the chemical industry is competitiveness the best way for these manufacturing companies to gain an advantage over other companies they compete with may be through integrated and innovative electrification, automation and digitization solutions.

By using process control and automation systems, production organizations can manage systems at lower cost, optimize process knowledge and increase energy efficiency (Edgar & Pistikopoulos, 2018).

Industrial automation systems and digitalization are the most important elements for businesses that aim to increase efficiency in engineering and operations, reduce operating costs and improve product quality. When it comes to digitalization and smart manufacturing, oil refineries and chemical industries in many parts of the world often have to address key issues related to data availability and consistency (Celik & Öztürk, 2017).

As in the chemical industry, the industrial automation and control systems applications of processes consisting of many different consecutive systems are called "process automation" concept. Chemical, Pharmaceutical, Iron-Steel and Cement etc. sectors can be given as examples of process industries. Digital services play an increasingly important role in decisions such as whether to analyze process and plant data, implement system components or simply improve processes.

Industry 4.0 aims to enable objects to communicate with each other and with people by monitoring physical processes with cyber-physical systems in modular smart factories, thus making decentralized decisions, that is, smart production.

Factories, machines and devices that are fully integrated and connected to an industrial network will be able to act intelligently and partially autonomously, requiring minimal manual intervention (Monostori, 2014).

The fourth industrial revolution, known as Industry 4.0, paved the way for the systematic implementation of the modernized energy grid to manage the ever-growing energy demand by integrating renewable energy sources (Faheem et al., 2018).

Using real-time and high-value support systems, smart manufacturing has made possible a coordinated and performance-oriented manufacturing initiative that responds quickly to customer demands, minimizes energy and material use, and radically improves sustainability, productivity, innovation and economic competition (Yuan et al., 2017). One of the biggest problems encountered in the chemical industry is the incomplete or erroneous projection of "process automation". Each wrong prescription made in production can cause serious damage to the business.

In the "Process Automation" applications in the chemical industry, the selection of the right instruments suitable for the process, the creation of the algorithm, and the selection of industrial automation and control devices are of great importance. After these are done correctly, the programming of the process and the creation of the desired correct data constitute the first step for Industry 4.0 applications. When these are not done correctly and properly, it may not be possible to build Industry 4.0 on the automation and control system (Kayar et al., 2018).

In this application, programmable logic control device (PLC) and human machine interface (HMI) industrial devices where system parameters are entered and monitored are used as industrial control system (Öztürk & Kayar, 2019). In order for the operators to control and monitor the production processes in a fast and mobile manner, the application was also operated on a tablet PC. Thus, the authorized operator can control the system from wherever it can connect to the industrial network in the factory and can monitor the operation of the system from anywhere.

In the system, a web-based software has been developed in accordance with the Industry 4.0 concept in order to read the desired information, to save it in the database (DB), to monitor the recorded data and to receive the desired reports by live communication with the PLC used as an industrial control system.

This application serves both a scientific and a practical purpose. This application, which is compatible with the Industry 4.0 concept, reveals the benefits of Industry 4.0. At the same time, the project details described in this article constitute a good example of "process automation" in which industrial automation and control systems and digitalization are together. It will also give new ideas to those who are trying to realize the fourth industrial revolution, which has been on the agenda recently.

This article first describes the basic concepts of industrial automation and control systems (Chapter 2). Industry 4.0 and technologies used in digitalization will be introduced in Chapter 3. In Chapter 4, "process automation" technologies used in the chemical industry will be mentioned. In Chapter 5, reactors frequently used in the chemical industry and their properties will be explained. Both "process automation" and Industry 4.0 application of the paint production system put into use in Chapter 6 will be explained. In Chapter 7, we talk about the benefits of this application and offer our suggestions for the development of the system.

2. Industrial Automation and Control Systems Basic Concepts

Industrial automation and control systems (IACS) is a term used to describe different control systems that include devices, systems and controls used to run and / or automate industrial processes (Boyes et al., 2018).

2.1. PLC

PLC devices are mostly used as a control system in industrial applications. PLC devices are long-lasting and reliable devices designed for industrial environments. However, hardware prices are high. In addition, a separate fee is charged for software licenses used to program PLC devices (Hoxha et al., 2016).Technical features of the CPU 1510SP-1PN model are shown in Table 1.

Table 1. Technical specifications of the CPU 1510SP-1PN model (Siemens AG-1, 2020)

Characteristics	**CPU 1510SP-1 PN**
Work memory for program, integrated	100 KB
Work memory for data, integrated	750 KB
Load memory	Plug-in via SIMATIC Memory Card
Command execution times	
Bit operations	0.072 μs
Word operations	0.086 μs
Fixed-point operations	0.115 μs

2.2. Distributed Input and Output modules (I/O)

Distributed I/O modules have been used in industrial automation and control systems in recent years. Similarly, the use of distributed I/O modules in 'Process Automation' applications has shown a rapid increase. Especially in "Process Automation" applications, the devices and sensors in the facility are distributed over a wider area. Figure 1 shows the application of distributed I/O models in four different regions.

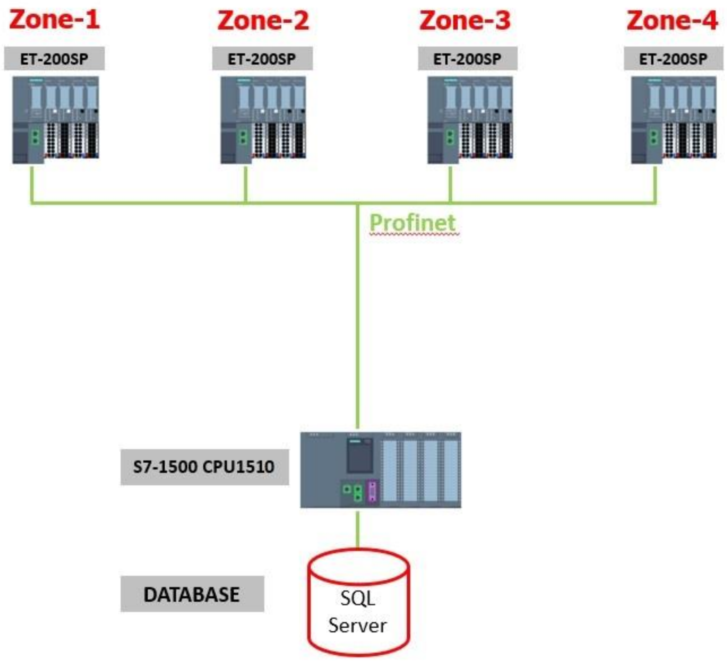

Figure 1. Application Example of Distributed I/O Modules

Distributed I/O modules are fully adapted to the plant structure with their modular, flexible and integrated structure. In addition, it provides significant savings in many areas such as cabling, assembly, engineering, commissioning and maintenance.

2.3. HMI

In "Process Automation" applications, one of the most used devices after PLC to monitor the operation of the process and to see warning and alarm messages are HMI devices. It is used to monitor the process instantaneously and to enter information into the PLC program. HMI devices have different models according to their technical specifications and screen sizes. Interfaces for control in HMI engineering process applications can be qualified as an information integration task. This is especially true for the configuration screens, which are the core element of the high-performance HMI (Urbas et al., 2012). The technical features of HMI KTP1200 basic OP are shown in Table 2.

Table 2. Technical Specifications of KTP1200 Basic OP (Siemens AG-2, 2020)

Characteristics	SIMATIC HMI KTP1200 BASIC
Display	
Design of display	TFT widescreen display, LED backlighting
Screen diagonal	12 in
Display width	261.1 mm

Display height	163.2 mm
Number of colors	65 536
Resolution (pixels)	
● Horizontal image resolution	1 280 Pixel
● Vertical image resolution	800 Pixel
● Numeric keyboard	Yes; Onscreen keyboard
● alphanumeric keyboard	Yes; Onscreen keyboard
Touch operation	
● Design as touch screen	Yes
● Diagnostic information readable	No

2.4. Industrial Network

Recently, with the use of Industry 4.0 and digitalization applications, the use of industrial network systems has also increased. Thus, the hardware and software costs of industrial network systems used to provide monitoring, control and diagnostics in industrial systems have been reduced. However, there are some application difficulties when these new technologies are applied in industrial settings. Given that the majority of these systems are made up of different distributed systems, management and coordination pose a significant challenge (Gholami et al., 2017).

3. Technologies used in Industry 4.0 and Digitalization

In order to talk about Industry 4.0 and digitalization, it may be useful to give a brief information about the main components that are most on the agenda. There are many different technologies within the Industry 4.0 concept. These technologies require separate expertise and competence on their own (Öztürk et al., 2019).

Autonomous robots, simulation, system integration, IoT, cyber security, cloud computing, additive manufacturing (AM), augmented reality (AR) and big data applications, which are considered as the basic components of Industry 4.0, are preferred for different purposes in automotive manufacturing lines (Kayar, 2020).

3.1. Industrial Internet of Things (IIoT) Applications

Information Technology (IT) and Automation technologies (OT) are growing at a fast and surprising rate. Especially in recent years, applications in the following subjects have increased significantly. For example; high-performance wireless and wired network, cloud-based data center, infrastructure, platform and software as a service, high-performance computing, high-performance databases, IoT devices, advanced model-based control and automation, artificial intelligence, real-time, high-fidelity modeling and high performance computing, visualization and virtual reality (Edgar & Pistikopoulos, 2018).

3.2. Cyber-Physical Management Systems

Cyber physical systems (SFS) connect the physical world with the virtual computing world with the help of sensors and actuators. Consisting of different constituent components, SFS creates global behaviors in collaboration. These components often include software systems, communication technologies, sensors / actuators, including embedded technologies, to interact with the real world.

Cyber Physical System (SFS) is a system that can effectively integrate cyber and physical components using modern sensor, computing and networking technologies (Zeadally & Jabeur, 2016).

3.3. Cloud Applications

Cloud computing promises to demand endless and inexpensive resources to provide appropriate infrastructure support for user applications. For this reason, it is increasingly accepted by many businesses trying to move their applications to the cloud to reduce costs and automate restructuring. These businesses are supported by free or private cloud platforms that support application deployment and restructuring in the cloud (Kritikos & Massonet, 2016).

Cloud security is one of the most important factors preventing the use of the cloud today. To overcome this reluctance, the cloud application development process must take into account potential security issues from the start and adapt to the flexibility offered by the cloud paradigm, while also taking into account the security constraints posed by developers and cloud customers (Casola et al., 2016).

3.4. Vertical and Horizontal Integration

In Industry 4.0 applications, the inclusion of all stages of the production processes in the system is called Vertical and Horizontal Integration. All interconnected systems, which should be the basis of Industry 4.0, must communicate with each other continuously and be able to monitor and control each other when necessary (Kayar & Öztürk, 2019).

3.5. Cyber Security

Much effort is being made to protect computer systems and networks. Despite the development and popularization of technologies, these techniques do not provide perfect security. Therefore, classification of normal or abnormal system activities and identification of vulnerabilities are among the important topics of cyber security research (Sun et al., 2018).

3.6. Big Data and Data Analytics

With the development of technology, the number of devices communicating with each other is increasing day by day, and the data produced grows accordingly.

The term big data has become popular over the past decade. Big data is used in traditional methods to analyze very large or complex data sets. In particular, it occurs in situations where big data cannot be easily stored or analyzed using spreadsheet programs such as Excel (Cobb et al., 2018).

4. 'Process Automation' Technologies used in The Chemical Industry

Pharmaceuticals, Iron-Steel and Cement etc. As in other industries, the chemical industry has also been made up of processes consisting of many different systems. Industrial automation applications of processes consisting of such different systems using industrial automation and control systems are called "process automation". There are different technologies used in "process automation" applications in the chemical industry. These technologies used are briefly described below.

4.1. Connection to Information Technology (IT) Systems

Nowadays, it is possible to monitor information in industrial applications live with network connections. Facilities in different locations can be connected to each other over the internet and viewed from anywhere in the world. Managers can access all the information they want from the production line, archives, warehouse information to analysis values, from anywhere.

4.2. IT Security

In process automation applications, IT security has become very important in recent years. Malicious people cause serious production losses by attacking production enterprises. Therefore, businesses should not be limited to a single security method and equipment (firewall), but basically based on closed safe cells as specified by the FDA in 21 CFR Part11.

4.3. Security of Process Automation System

In many process industries, permanent and fatal damages can occur to equipment, people and facilities as a result of errors or malfunctions. Strong and durable hardware and software security systems are used to prevent the occurrence of such hazards in the process and to minimize risks.

4.4. Batch Automation

Batch control can be defined as the production of different number of semi-finished inputs by passing through certain processes in a certain period of time. Batch production may take days, weeks or months depending on batch or continuous production. They are the most common "batch control" applications, especially in process automation applications. The final product to be produced is always aimed to be of the same quality. Batch quality has increased significantly with the use of industrial automation systems in process applications. Ensuring that production is always at the same quality is possible with the design of a good automation and control systems. It is necessary to wait for the batch production to be completed in order to understand whether the batch production has been done correctly (Kayar et al., 2019).

5. Reactors used in The Chemical Industry and Their Properties

Process control is a vital component in the production of the main product in the reactor. Semi-finished inputs with different numbers and characteristics are taken into the reactor and passed through certain processes in a certain period of time to produce the main product. Controlling the reactor system is an important key to increasing product yield, reducing defective product, increasing capacity and thus success in the competitive market in manufacturing enterprises. The most used reactors are "Polymerization Reactor" and "Stirred Tank Reactor".

5.1. Polymerization Reactor

The 'polymerization reactor' is an integral part of many chemical processes. Polymerization reactors can be designed for continuous and discontinuous processes of different volumes. The propylene polymerization process is one of the chemical processes that occur in the fluidized bed reactor. The gas monomer is fed from the spreader to react with the solid catalyst particles inside the reactor. Polymer particles are produced from a heterogeneous exothermic polymerization reaction (Jongpaijit & Bumroongsri, 2017).

Gas phase polymerization is a method commonly used in the polymer production process. The heterogeneous reaction between the monomer gas and the solid catalyst takes place in the fluidized bed reactor to produce the polymer product. The design and production planning of this process is a difficult task due to the complex fluid behavior and polymerization reaction inside the fluidized bed reactor (Kusolsongtawee & Bumroongsri, 2017).

5.2. Stirred Tank Reactor

The "Stirred Tank Reactor" is based on a standardized and structured design of the automation program using predefined equipment and control modules. The mixed tank reactor is the most used reactor in the chemical process and pharmaceutical industry due to its high mixing efficiency that increases the production rate in heterogeneous reactions. The mixing efficiency of the standard agitated trough depends on the impeller geometry, physical properties of the solution and the properties of the stub plates (Mc Cabe, W.L., Smith, J.C. and Harriot, 1985).

6. Application Example

This article makes paint production of a chemical factory in Turkey 'Process Automation' project implementation were discussed. In this project, the commissioning work was carried out, first all steps of production were digitized and the industrial automation application of the factory was commissioned. Later, a web-based production management system was developed for a solution suitable for the Industry 4.0 concept.

6.1. Current Status of the Facility

In order to transform the facility with an unsuitable digital infrastructure, renewal of the existing automation systems was requested. In addition, it has been observed that there is a need for a fully integrated IT infrastructure and network structure that controls all production elements, materials and equipment. The database management system for data-driven services was not available at the facility. Heterogeneous IT environments have been identified as an important problem for real-time collection and archiving of manufacturing data, analysis and reporting. The facility had to be configured in accordance with the Industry 4.0 infrastructure. For a solution suitable for the Industry 4.0 concept, a web-based production management system was needed in addition to the digitalization of production processes.

6.2. Topology Structure of the System

When the topology of the system is examined, a Siemens Simatic S7-1500 PLC CPU 1510SP 1 PN is used as the control system. In order for the operator to monitor and control the system, a Siemens Simatic HMI operator panel KTP1200, a Scada system to monitor and control from the control room, and a tablet PC communicating via wi-fi is used to monitor and control the system from any part of the operator. In addition, a PC and a server system, running the Industry 4.0 software, were used to read the relevant information from the PLC and save it in the database. There is a Siemens Scalance XB005 industrial switch that enables all these devices to connect and communicate in the same industrial network. The topology of the system is shown in Figure 2 below.

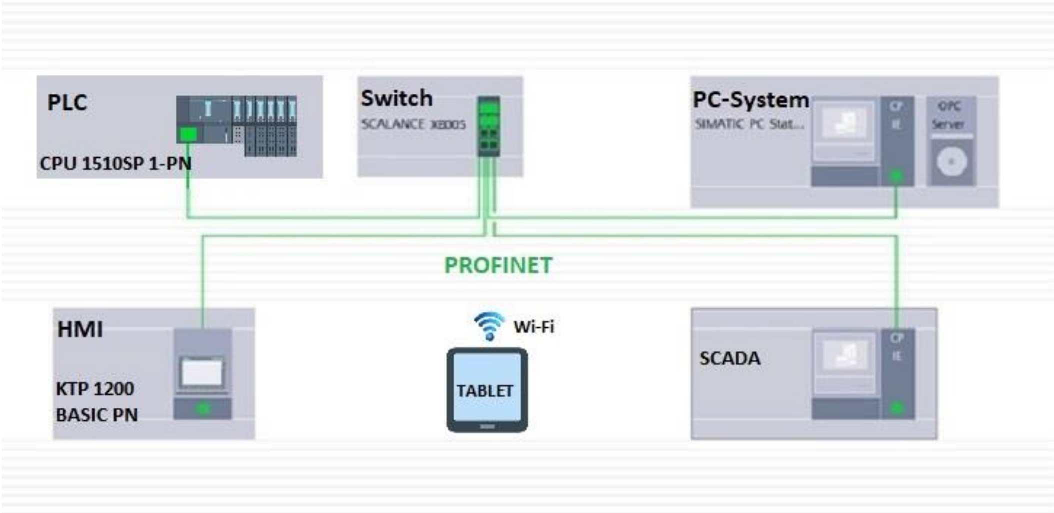

Figure 2. Topology Structure of The System

6.3. 'Smart Reactor' Industry 4.0 Software

A web-based special software has been developed for the chemical industry paint production line. Nowadays, where digitalization is applied to almost every sector, both the control and monitoring of the process is provided with this software suitable for the Industry 4.0 concept developed for the chemical industry. A new interface has been designed to control and monitor a total of 12 chemical tanks, 6 reactors, oil boiler, water tower, cold room and compressor. This software is designed for two user levels. At the first level, it is the 'user' level that is only allowed to monitor, and at the second level, it is the 'authorized' level that is allowed to monitor, report, adjust and choose the language. This web-based software can be operated from a PC, mobile phone or tablet PC. The interface screen is seen in Figure 3.

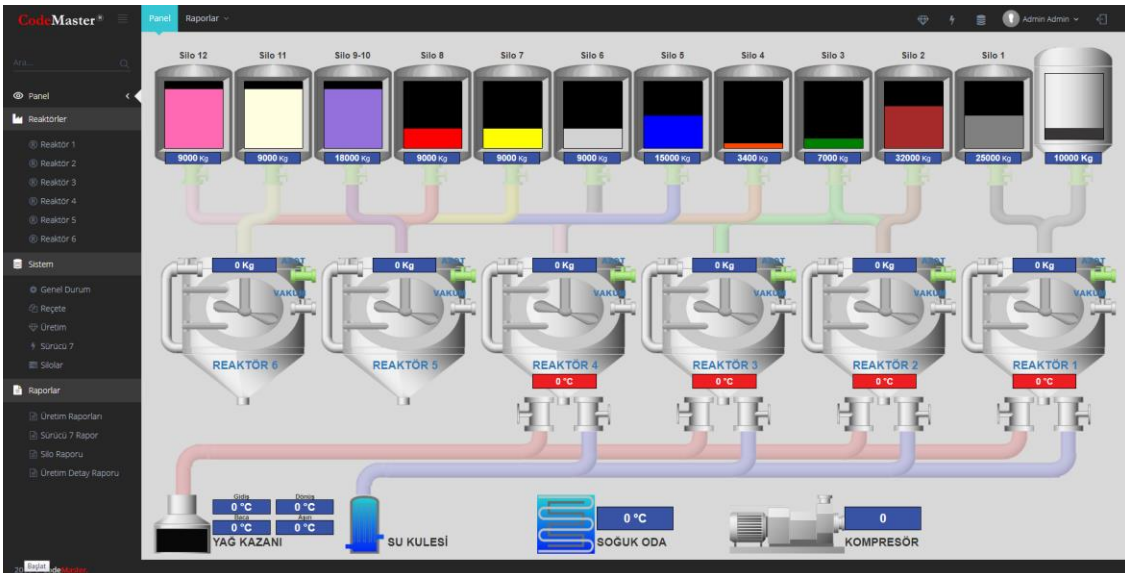

Figure 3. Interface Screen Shot

6.3.1. Working Principle of Reactors

A separate worksheet is defined for each reactor. The operator selects the reactor he wants and reaches the relevant reactor page. The relevant silos where each reactor will receive chemical material are shown in the worksheet. For example, Reactor 2 can only receive chemical material from Silo 2, Silo 3, Silo 6 and Silo 12. In the Table 3 below, the information that the operator can monitor and intervene in is shown on the interface page of the reactor 2.

Table 3. Information on The Reactor Page

Pos.	Name	Description
1	Reactor pressure	Actual pressure of the reactor (bar)
2	Reactor temperature	Reactor actual temperature (℃)
3	Reactor weight	Reactor actual weight (kg)
4	Silo 2 weight	Actual weight (kg) of Silo 2 feeding Reactor 2
5	Silo 3 weight	Actual weight of Silo 3 feeding Reactor 3 (kg)
6	Silo 6 weight	Actual weight of Silo 6 feeding Reactor 6 (kg)
7	Silo 12 weight	Actual weight of Silo 12 feeding reactor 12 (kg)
8	Reactor set top temperature	Rector's desired temperature upper value (℃)
9	Reactor set lower temperature	Rector's desired temperature lower value (℃)
10	Reactor cooling set	Reactor set cooling upper temperature value (℃)
11	Reactor cooling reset	Reactor set cooling lower temperature value (℃)
12	Pump operating modes	Pump operating mode manual-auto-semi-auto
13	Vacuum valve open / close	Open / closed state of the vacuum valve
14	Driver 2 operating modes	Driver 2 operating modes manual-auto-semi auto
15	Time entered	Working time of the reactor

Production processes can be tracked online and all notifications can be received simultaneously from the web-based interface screen and mobile application in our "Smart Reactor" application. Figure 4 shows the reactor control and monitoring screen.

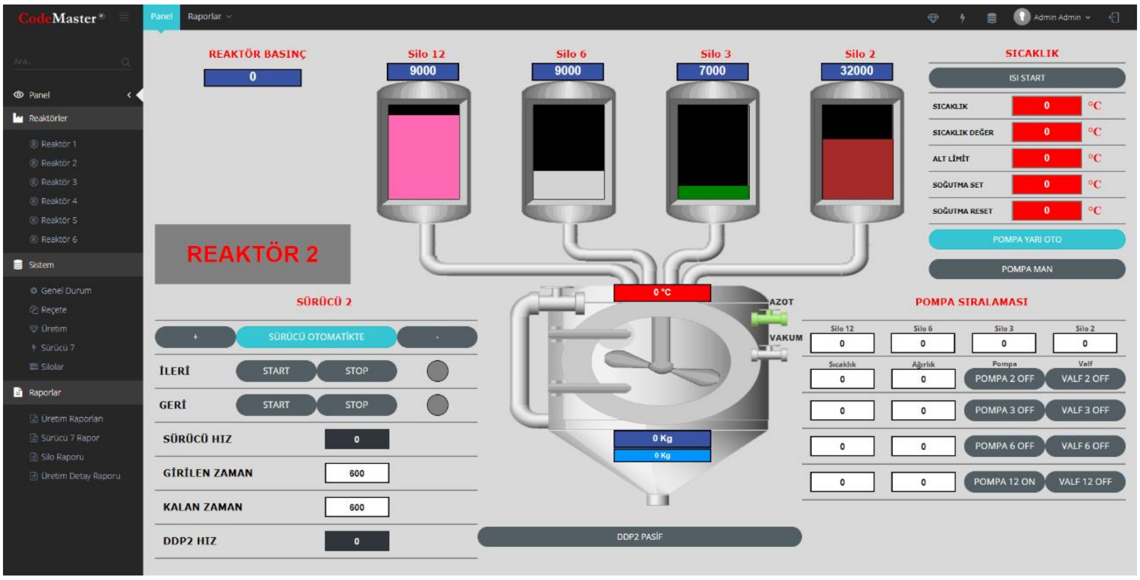

Figure 4. Reactor Control and Monitoring Screen

6.3.2. Getting Reports

A person at the authorized level can create reports using 6 different reporting options in four different sections: production report, motor drivers report, silos report and detailed report of production. The generated reports can be converted to Windows word, excel or .pdf format. The headings of the report generated for the silos are listed in Table 4 below.

Table 4. Reporting Headings of Silos

Pos.	Name
1	Sequence No
2	Silo No
3	Reactor No
4	Date / time transfer started
5	Transfer time
6	Transfer amount / kg

The report generation interface of the silos can be seen in the Figure 5 below.

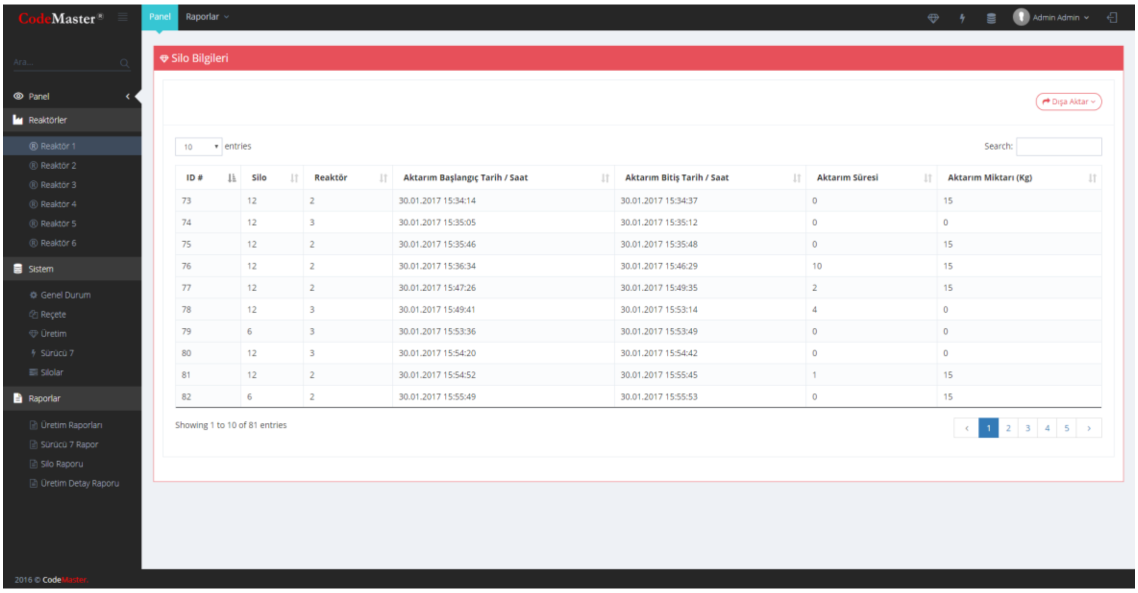

Figure 5. Report Generation Interface Screen of Silos

7. Conclusion

Production companies all over the world have to struggle seriously with their rivals. As in every sector, one of the most important factors in the chemical industry is to gain an advantage over its competitors. For this, it is of great importance that all production processes are controlled, monitored and managed correctly. With the "Smart Reactor Production Monitoring System" project commissioned and implemented, all steps of the production processes have been digitalized.

At the field level, industrial control and automation applications and Industry 4.0 software, which enables the monitoring and reporting of data, is observed to achieve an increase in productivity of nearly 30% in the paint production facility.

All process information of the production and all sensor information collected from the field are instantly recorded in DB. Thus, the business has gained the usability of past production data and the ability to analyze. Accordingly, it was observed that 40% faster production was achieved in the production process. Thanks to the analysis based on real semi-finished product consumption information, correct material planning has been ensured, which significantly reduced the company's raw material costs.

With Industry 4.0 software, all processes of production are monitored instantaneously, and a malfunction in the system is detected by authorized persons as soon as possible and its solution is provided. Thus, the production is ensured to work without errors for a long time. In a continuous and error-free production system, the efficiency of the production reaches the highest level.

It is very fast and easy to reach temperature values, which are very important for production. By using this information, managers who make production planning can determine both the number of personnel they will employ and the qualifications of the personnel more easily and quickly. This has enabled the company that produces paint to do the employee optimization correctly and increase the productivity, thus reducing the personnel costs.

It is possible to establish a more technological system by improving the industrial control and automation application and Industry 4.0 software of this established system. Our recommendations regarding this can be listed as follows.

1) By ensuring full integration of this established system with the ERP system, all business processes can be integrated with production.
2) A barcode with a production description can be written on all filled paint cans. Thus, the production life cycle of each paint can will be controlled.

At the same time, this system makes the production of paint applied to other businesses in Turkey. In these enterprises, they will contribute to the digital transformation of our country by ensuring the digitalization of production processes.

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