IPTEK, The Journal of Engineering, Vol. 10, No. 1, 2024 (eISSN: 2807-5064)

Implementation of Air Sweep to Prevent Blockages on The Salt Crystallization Process

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Abstract

In the process of crystallization salt, blockages often occur due to the large amount of salt that sticks to the wall's hopper of the crusher machine. Seeing this condition, a Salt Cleaning Tool was designed using the air sweep method. In the first step of the design, a survey was carried out to find out how thick and the area of salt that sticks over a certain period. Furthermore, experiments were carried out to determine the position of the nozzle and the air pressure needed to knock out the salt attached to the hopper. The control system uses Arduino hardware as a micro controller tool. The experimental results require that the spray direction is tangential to the hopper surface, so the nozzle on the market needs to be modified. Likewise, an air pressure of 6 bar .is required and a burst time period of every 3 seconds with a nozzle opening time of 250 milliseconds with the condition that three solenoids are open together. Modification of the nozzle The control system uses Arduino hardware as a micro controller tool. The implementation of the air sweep as a salt cleaning tool has been successful, this is evidenced by operation of the crusher machine without problems.

Keywords: Air sweep; Hopper; Nozzle

1. Introduction

The salt production process in the Salt Industry is carried out by means of multilevel processing, where the seawater evaporation process is carried out in the evaporator area and the crystallization process is carried out in the crystallization area. In the crystallization process, the first stage of salt is put into the hopper to be crushed in the crusher machine I, then washed in the washer machine. After that, it is crystallized in the evaporator and then crushed in the second stage in the crusher machine II. Considering that the water content in the salt is still high, in this process salt often sticks and causes buildup on the hopper walls. this results in a blockage of the outlet. To overcome this the operator beats the outer wall of the hopper so that the adhering salt can fall out. If it's too late, the pile of salt that sticks will get bigger and the salt will harden. So that the adhering salt can be released, the operator does the cleaning by pushing it manually using a shovel (stainless steel). The action of beating the outer wall of the hopper can cause damage and leaks, so the production process must be stopped and the hopper wall must be repaired frequently with the welding process. This condition can disrupt the salt production process and increase maintenance costs. In order to reduce the costs incurred in the context of stopping the production process and adding employees in charge of cleaning the hopper walls and the cost of repairing this product-based research is intended to design and develop a salt cleaning tool using an air sweep system. Some of the advantages of compressed air systems that they are widely used in automated production systems include easy storage, simple in design and management, many choices of movements (linear, rotary, angular, and others), relatively low cost, reliable, no impact on the environment, safe [1]. In addition to the above advantages, pneumatic machines are usually clean, easy to integrate, and have a high power/weight ratio, so when compared with other alternative technologies they have an initial investment advantage of 10:1 [2].

Air sweep systems are used for fast, uninterrupted flow of bulk material. It can be used for granular and fine materials as well as for dense and entangled materials such as salt. In addition, it is also cost and energy-efficient, moves very fast and flows are well-controlled [3]. This method was chosen because it is the most effective and inexpensive method in solving problems and is expected to help increase the effectiveness of the production process and help reduce maintenance costs. So, the goal of this research is to design and make an air sweep system equipped with control device that functions to circulate compressed air to the nozzle. There are 6 types of compressed air control modes on the compressor, start/stop, load/unload, inlet modulation, auto-dual, variable displacement, and variable speed control [4].

2. Method

The method of implementing the activity starts from collecting data by conducting field surveys. Other activities to support preparation include conducting a literature study to search for and study library materials obtained from various sources including textbooks, scientific publications, and catalogs on air sweep components.

2.1. Problem Identification

Problem identification is carried out in order to obtain a solution for cleaning salt attached to the hopper wall which can cause blockages and result in hampered production processes. The results of field observations will be used as a reference in the process of designing and manufacturing sweep air salt cleaning systems. So that the purpose of identification is carried to: a) Know the operating conditions and dimensions of the crusher machine hopper II b) the Position/location of salt attached to the hopper wall. c) Thickness and volume of salt attached to the hopper wall for a certain time d) properties of salt attached to the surface of the machine. Figure 1 shows the crusher machine and measurement of the wall hopper. Figure (2a) shows the thickness and position of the salt attached to the wall and Figure (2b) shows the damage to the hopper wall.

Figure 1. Crusher Machine II and Measurement of Wall Hopper

Figure 2. The Thickness and Position of the Salt Attached to the Hopper Wall (a), Damage to the Hopper Walls (b)

2.2. System Design and Technology

Based on the results of the site survey and literature study, an air sweep system was designed. This method was chosen because it is easy to manufacture, and the operational costs are relatively cheaper.

Advantages of pneumatic air sweep system [5]:

1) Air is available almost everywhere and in unlimited quantities.
2) Air can easily flow through the pipes, even over longer distances.
3) The compressor does not need to operate continuously, because it can be stored in the reservoir.
4) Compressed air is insensitive to temperature fluctuations, so it operates reliably even under extreme temperature conditions.
5) Compressed air does not pose a risk of explosion or fire.
6) Clean compressed air because air escaping through leaky pipes or elements does not cause contamination.
7) The operating components are simple in construction.
8) Compressed air is a very fast acting medium; The cylinder has a working speed of up to 2 m/sec.
9) Pneumatic tools and operating components can be loaded to a stop and are therefore overload safe.

Weakness:

1) Compressed air requires good preparation. There should be no dirt and condensate, so the system must be clean.
2) Because fluids are compressible, it is not always possible to achieve uniform and constant results with compressed air.
3) Economically compressed air only up to force requirements under normal working pressure of 6-7 bar and depending on travel and speed, output limits between 2000 - 3000 kg.
4) The exhaust air sounds loud, so a sound suppression system is needed.

The results of the design were then design drawings of the air sweep system, frame specifications and supporting equipment. The air sweep system consists of 3 nozzles, a solenoid attached to the hopper wall and other components such as a controller, hose, Filter-Regulator, and compressor. The nozzle functions to convert pressure energy into kinetic energy at jet speed, while the compressor provides pressurized air. Figure 3 shows the design of a salt cleaning system using the air sweep method.

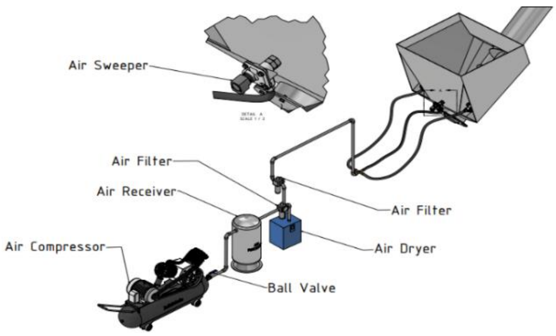

Figure 3. Schematic Block Diagram of the Air Sweep System

After designing the air sweep system, the nozzle modification manufacturing process is carried out. Considering that the nozzle used is not available in the market, modifications to the shape of the stem and head of the nozzle on the market are carried out. Figure 4 shows the design drawings of the modified stem and nozzle head shapes.

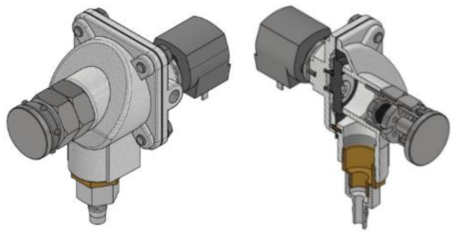

Figure 4. Modification of Stem Shape and Nozzle Head

2.3. Experiment Methode

The experimental method begins with testing to determine the optimal pressure that can thresh the salt attached to the wall. This test was carried out by simulating a prototype hopper that was coated with 5 cm thick salt. In this experiment, it was determined that the nozzle opens 20 times per minute or every 3 seconds with an opening time (duration) of 250 milliseconds. Furthermore, pressure variations were carried out at 6 bar and 8 bar as well as valve opening variations of 2 mm and 4 mm. The results of this experiment can be seen in Table 1 below. Figure 5 below shows the prototype hopper with the attached nozzle. Figure 6 shows the threshing results at a pressure of 6 bar.

Figure 5. Prototype Hopper with Attached Nozzle

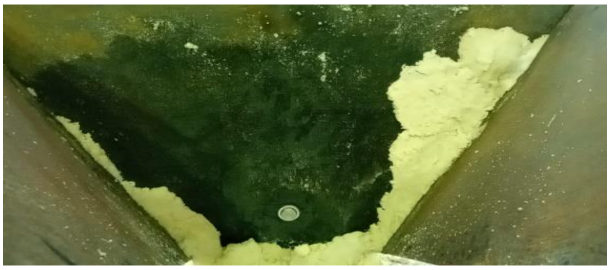

Figure 6. Results of Threshing at a Pressure of 6 Bar

From the experimental results, the optimal pressure for threshing salt in the crusher machine hopper is shown in Table 1.

Tabel 1. Threshing Area at Various Pressures and Nozzle Openings

No	Pressure	Clearance Nozzle	Salt Threshing	
			Length	Wide
1	6 Bar	2 mm	10 cm	8 cm
2		4 mm	9 cm	10 cm
3	8 Bar	2 mm	10 cm	11 cm
4		4 mm	10 cm	12 cm

In the table above it can be seen that between 6 bar and 8 bar pressure, both can thresh the salt stuck to the wall. If the nozzle is placed at the bottom of the wall (near the hopper inlet), then the salt that clogs the hopper inlet will fall out and the salt that sticks to the top wall will also fall out due to gravity. Therefore, to save compressor work, a pressure of 6 bar is taken with a nozzle valve opening of 2 mm. This consideration is also based on the availability of pneumatic equipment available on the market, all of which have a working pressure of 6 Bar.

Next, the experiment was carried out in real hopper conditions. There are 4 walls of the hopper, one of which is perpendicular, and 3 walls have a slope. Three nozzles are placed on the bottom wall which has a slope. Settings are made by opening the three nozzle valves alternately with an interval of 3 seconds. The first setting is 1,1,1, which is done by opening the valves one by one, the nozzles open alternately with an interval of 3 seconds. The second setting is 2.1, which is done by opening 2 nozzle valves simultaneously and closing one nozzle with an interval of 3 seconds. The third setting is that the 3 nozzle valves open and close simultaneously at 3-second intervals. From the method of setting the valve opening, the third setting is the most effective for sweeping away the salt that sticks to the hopper walls

3. Results and Discussion

3.1. Actual Air Consumption

The air capacity needed to threshing the salt that attaches to the hopper in the crusher machine is based on the air-sweep catalog available on the market as a reference in calculating the required air [6]. As Each nozzle opening lasts 250 milliseconds with an opening period of every 3 seconds so, at pressure 90 psi requires a delivery capacity of 2.18 ft^3/sec standard air.

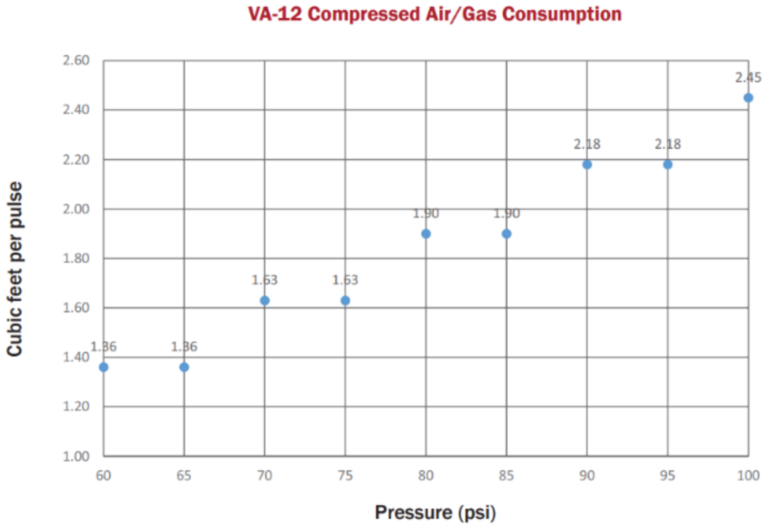

Figure 7. Graphic of Consumption Compressed Air Per Nozzle [6]

From Graphic Figure 7, capacity every pulse per nozzle of standard air:

$$Q = 2.18 \frac{ft^3}{\sec - nozzle} \tag{1}$$

Capacity per nozzle of standar air

$$Q = \frac{n}{t} \tag{2}$$

$$Q = 2.18 \frac{ft^3}{3\sec - nozzle} \; x \; \frac{(0.3048m)^3}{1\, ft^3} \tag{3}$$

$$Q = 0.0205 \frac{m^3}{sec{-}nozzle} \tag{4}$$

Capacity 250 milliseconds and for 3 nozzles when opening simultaneously:

$$Q = \frac{250}{1000} \; x \; 0.0205 \frac{m^3}{sec{-}nozzle} \; x \; 3 \; nozzle \tag{5}$$

$$Q = 0.0154 \; \frac{ft^3}{sec}$$

By considering a safety factor of 10% [7], then:

$$Q = 1.1 \; x \; 0.0154 \; \frac{ft^3}{sec} \tag{6}$$

$$Q = 1.014 \; \frac{m^3}{min} \tag{7}$$

3.2. Selection Of Pipe Diameter

In designing a compressed air system, pipes, and fittings are needed to be able to help flow compressed air from the compressor to the nozzle. Pipeline design is carried out based on the location conditions of the hopper crusher machine and compressor. Figure 8 below shows the design of the air-sweep pipe installation.

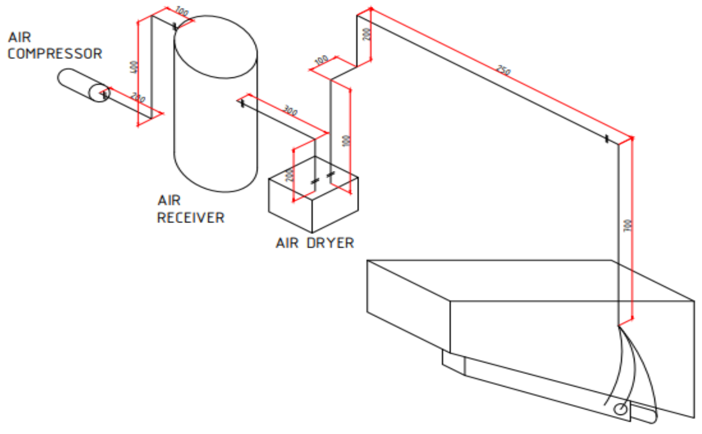

Figure 8. Isometric Drawing of Piping Installation

To find the pipe diameter using the formula [7] (esposito):

$$D^{5.31} = \frac{0.1025\, L\, Q^2}{CR \times P_f} \tag{8}$$

Where:

D = Diameter of pipe (in)

L = Length of pipe = 10 m = 32.8 ft

p_f = pressure drop with safety 0.5 bar = 7.25 psi

CR = compression ratio = 7.9

From Figure 8. above it is known that the length of pipe is *l* = 10 meter = 32.8 ft.

So, equation become:

$$D = \sqrt[5.31]{\frac{0.1025\, L\, Q^2}{CR \times P_f}} \tag{9}$$

$$D = \sqrt[5.31]{\frac{0.1025 \times 32.8 \times 0.597^{\,2}}{7.9 \times 7.25}} \tag{10}$$

$$D = 0.483\ in \tag{11}$$

From the calculation, the minimum diameter of the piping installation from the branch to the nozzle is 13 mm or 0.5 inch. Thus, the type of air 45 series ISO 2398/A1 ½-inch Synthetic rubber was chosen with an inside diameter of 13 mm, an outside diameter of 21 mm, and a maximum working pressure of 15 bar [8]

3.3. *Selection Of Pipe Diameter*

Calculation of pressure drop in pipe can use the equation below [7]:

$$P_f = \frac{0.1025\, L\, Q^2}{CR \times D^{5.31}} \tag{12}$$

So:

$$p_f = \frac{0.1025 \times 32.8 \times 0.543^{\,2}}{7.9 \times 0.622^{5.31}} = 1.56\ psi = 0.101\ bar \tag{13}$$

3.4. *Pressure Drop in Fittings*

The type and number of several fittings contained in the installation can be shown in table 2, where the equivalent length is taken from [7] [9].

Table 2. Equivalent Length of Various Fittings [7]

No	Fitting	Le (ft)	Qty	Total (ft)
1	Elbow 90	1.7	7	11.9
2	Tee (through branch)	3.3	1	3.3
3	Tee (through run)	0.7	1	0.7
4	Gate valve (fully open)	0.35	1	0.35
5	Globe valve (fully open)	18.6	1	18.6
				34.85

So, Pressure drops in fitting:

$$p_f = \frac{0.1025 \times 34.85 \times 0.543^2}{7.9 \times 0.622^{5.31}} = 1.66\, psi = 0.114\, bar \tag{14}$$

The pressure drops in the air dryer and air receiver tank are assumed to be 0.3 bar each [9] and pressure drop in FRL 0.1 bar, so total pressure drops are 0.7 bar.

$$Total\ pressure\ drop = 0.101 + 0.114 + 0.7 = 0.915\, bar \tag{15}$$

3.5. *Air-Receiver Volume*

In sizing the air receiver, the conditions that must be known are the standard air consumption required by the air sweep system and the capacity of the compressor. The standard air requirement in the air sweep system is Q = 0.0154 m^3/sec = 0.924 m^3/min.

The maximum air capacity requirement for the compressor is calculated by considering the leakage factor (10%), safety (10%) and reserve air requirement (20%). So that the total additional capacity is assumed to be 40% of the system requirement. Thus, the maximum normal air requirement:

$$Q = 1.4\, x\, Q \tag{16}$$

$$\mathrm{Q} = 1.4 \text{ x } 0.0154\ \frac{m^3}{sec} = 0.0216\ \frac{m^3}{sec} = 1.3\ \frac{m^3}{min} \tag{17}$$

The volume of air-receiver can be calculated through the following equation [10]:

$$V_r = \frac{101\, t\, (Q_C - Q_S)}{P_{max} - P_{min}} \tag{18}$$

Where:

t = The time needed to fill the receiver tank to full, assumed (t = 5 minute).
Qc = Compressor Capacity = 1.3 m^3/min
Qs = Air sweep system capacity = 1.014 m^3/min
P_{max} = Maximum pressure of the air receiver = 10 bar = 1.000 KPa
P_{min} = Minimum pressure of the air receiver = 7 bar = 700 KPa

Volume of receiver tank when the system is not operating and the tank is empty:

$$V_r = \frac{101 \times 5\, min \left(1.3\, \frac{m^3}{min} - 0\, \frac{m^3}{min} \right)}{1000\, kPa - 101\, kPa} = 0.73\, m^3 \tag{19}$$

According to the ASME recommendation TABLE 3, is selected the volume of the air receiver V_r = 0.8 m^3 = 200 gallons, so the maximum capacity not exceeding ASME standards Q = 340 m^3/hr. So, the time needed to fill the air receiver when the system operates with a capacity of Q = 1,014 m_3/min can be calculated as follows:

$$t = \frac{V_r\, (P_{max} - P_{min})}{101\ (Q_C - Q_S)} \tag{20}$$

$$t = \frac{0.8\ (1000\, kPa - 700\, kPa)}{101 \times (1.3\, \frac{m^3}{min} - 1.014\, \frac{m^3}{min})} = 8.3\ minutes \tag{21}$$

Table 3. ASME Recommended Air Receiver Volume [10]

Airflow Capacity		Recommended Receiver Volume		
CFM	m^3/hr	ft^3	Gallons	m^3
100	170	13	100	0.4
200	340	27	200	0.8
300	510	40	300	1.1
400	680	54	400	1.5
500	850	67	500	1.9
750	1275	101	750	2.9
1000	1700	134	1000	3.8
1500	2550	201	1500	5.7
2000	3400	268	2000	7.6
3000	5100	402	3000	11.4
4000	6800	536	4000	15.2
5000	8500	670	5000	19.0
7500	12750	1005	7500	28.5
10000	17000	1340	10000	38.0

3.6. *Selection Compressor*

In calculating the actual capacity, considering the volumetric losses, the volumetric efficiency can be calculated using the equation below [10].

$$Nv = 1 - \varepsilon \left\{ (rp)^{\frac{1}{n}} - 1 \right\} - L \quad (22)$$

Where:

ε = Percent clearance = 0.05

L = non-lobe (0.03 ÷ 0.07) = 0.05

n = polytropic exponent = 1.2525

So, the volumetric efficiency:

$$Nv = 1 - 0.05 \left\{ (10.87)^{\frac{1}{1.25}} - 1 \right\} - 0.05 = 0.76 \quad (23)$$

In choosing a compressor based on a capacity requirement of Q = 1.7 m^3/min = 60.03 cfm and a pressure ratio = 10.86 then according to Figure 9, a screw compressor is selected.

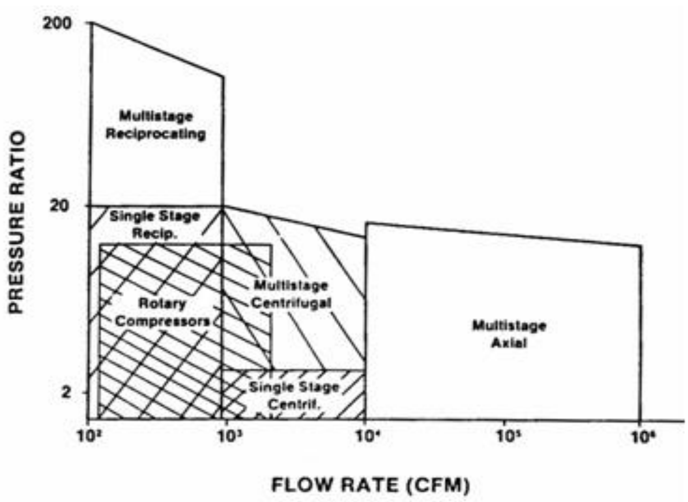

Figure 9. Compressor Selection Diagram

Thus, the actual capacity of the compressor:

$$Q_{C(act)} = \frac{Q_c}{h_V} = \frac{1,3}{0,76} = 1,7\ \frac{m^3}{min} = 0,0283\frac{m^3}{sec} \quad (24)$$

3.7. *Compressor Shaft Power*

The polytropic power (Shaft Power) needed by the compressor to run the pneumatic system can be calculated using the following equation, [11]:

$$Wshaft = \frac{m\ x\ n}{n-1}\ x\ Ps\ x\ Qsuction\ x\ [(\frac{Pd}{Ps})^{\frac{n-1}{m\ x\ n}} - 1 \quad (25)$$

Where :

M = number of stages (1)

N = polytropic exponent = 1.25

Qs -= inlet capacity (0.028 m³/s)

So, Shaft power (Wcom) :

$$Wshaft = \frac{1.25}{1.25-1}\ x\ 101325\ Pa\ x\ 0.0283\ x\ [(10.87)^{\frac{1.25-1}{1.25}} - 1 \quad (26)$$

$$Wshaft = 8.77\ Watt = 0.0877\ kW \quad (27)$$

3.8. *Calculation Of Motor Power*

In calculating the driving power of the compressor, it is necessary to know in advance the type of prime mover and the type of transmission used. In this condition, the type of electric motor drive with pulley & belt transmission is selected. So that the calculation of motor power can use equation (7) below [11]

$$Wmotor = \frac{1.25}{\eta T}\ x\ (1 + \alpha\ ) \quad (28)$$

Where :

ηT = transmission efficiency (0.95)

α = reserve factor (for induction motor = 0.1÷0.,2)

Wshaft = shaft power (8.77 KW)

So that :

$$Wmotor = \frac{8.77}{0.95}\ x\ (1 + 1.15\ ) \quad (29)$$

$$Wmotor = 10.61\ kW \quad (30)$$

For a compressed air system with a capacity of 1.7 m³/min and a maximum pressure of 10 bar, a single stage, oil-free, screw compressor with a motor power of 11 KW (Model GTO11F and ¾ inch pipe size) was chosen [13].

3.9. *Air Dryer Selection*

In calculating the correction capacity of the air dryer, it is based on the capacity and maximum operating pressure. Air capacity requirements can be calculated using the following equation [12].

$$Corrected\ Flow\ Rate = \frac{Compressor\ flow\ rate}{CF\ \{TCF;PCF\}xDCF} \quad (31)$$

Where:

TCF = inlet temperature (40 ^{0}C)

PCF = inlet pressure (10 bar)

DCF = Dewpoint correction factor (1)

CF = for (p=10 bar & T=40 ^{0}C),

Correction factor =0,96 (from Fig 8)

Table 4. Correction Factor For Sizing Air Dryers

Temp (°C)	**Bar g**						
	4	**5**	**6**	**7**	**8**	**9**	**10**
30	0.69	0.80	0.90	1.02	1.06	1.17	1.29
35	0.44	0.62	0.80	1.00	1.05	1.16	1.28
40	0.28	0.42	0.59	0.70	0.79	0.88	0.95

So that :

$$Corrected\ Flow\ Rate = \frac{1.7\,\frac{m^3}{min}}{0.96\ x\ 1} = 1.77\ \frac{m^3}{min} \tag{32}$$

So based on the Ingersoll Rand catalog, the D127EC Cycling Refrigerated Dryers air dryer was chosen with a capacity of 127 m^3/hr [15].

3.10. Designing the Control System

The next step is to design the control system. In designing the control system, it is necessary to have a block diagram so that the control system runs as desired. Figure 10 shows the block diagram of the control system. Furthermore, the block diagram is implemented in the wiring diagram and is used to create an electronic circuit for the control system of the air sweep salt cleaning equipment. Figure 11 shows the Wiring Diagram of the Control System on air-sweep Salt Cleaning Equipment.

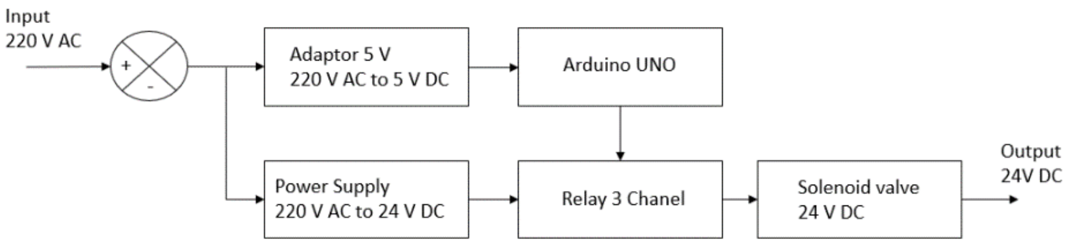

Figure 10. Control System Block Diagram

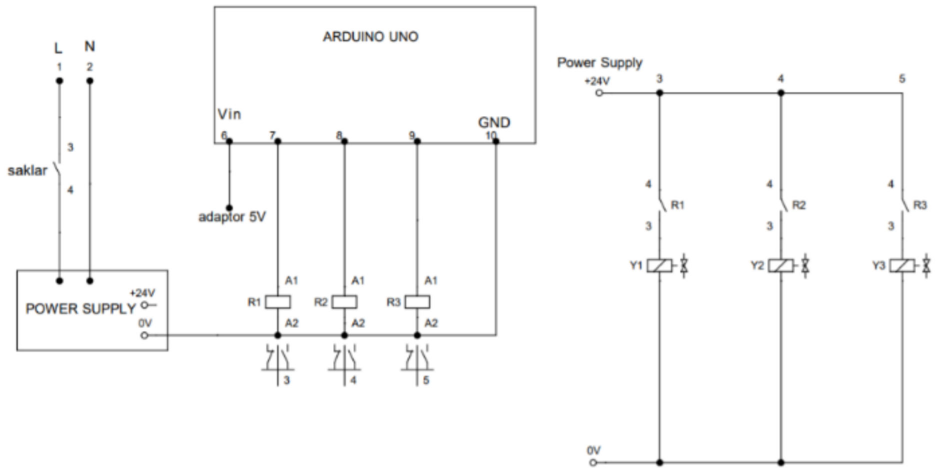

Figure 11. Wiring Diagram of the Control System on an Air Sweep Salt Cleaning Machine

5. Conclusions

From the results of the discussion, the conclusions that can be explained are the use of air sweep to prevent clogging in the salt crystallization process in the hopper of the crusher machine has been successfully implemented. It takes 3 nozzles that open simultaneously every 3 seconds with a time of 250 milliseconds, the total required capacity is Q = 1.014 m^3/minute and the minimum pressure is 6 bar. Selected hose type of air 45 series ISO 2398/A1 ½-inch Synthetic rubber, outer diameter 21 mm with a total pressure drop = 0.95 bar. The volume of air receiver tank Vr = 0.8 m^3 = 200 gallons and an air dryer type Cycling Refrigerated Dryers with a capacity of 127 m^3/hr are selected. Selected oil free screw compressor with a capacity of Q=1.7 m^3/minute, maximum pressure of 10 bar and motor power of P =11 KW.

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