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Senior Design Project Report

Design and Experimental Study on air-Dehumidification Performance using Supersonic Nozzle

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Natural gas is most often mixed with significant quantities of water and others unwanted solid particles. Moreover, these unwanted particles can cause many serious problems to the carrier means, instrumentations, and flow transmission itself. Supersonic nozzles are commonly used to purify the air. As an innovated technology, it is employed to overcome the deficit of the traditional method, related to gas dynamics, thermodynamics and fluid dynamics theory. In this project, an indoor test rig will be built to study the dehumidification process of moisture fluid. Humid air is chosen for the study. The working fluid will be circulating in an open loop, which has provision for filtering, metering, and humidifying. A stainless steel supersonic separator will be designed and constructed together with the C-D nozzle system. Dehumidification process performance of humid air using supersonic nozzle will be studied. The nozzle and separator will remain the same as the previous study we will change only the diffusers. We will investigate three new designs of diffuser portion in the supersonic nozzle system in terms of separation efficiency of the natural gas. We achieved in our study 18% humidity level with 50mm diffuser and 17% with 70mm and 90mm diffusers with 2mm inlet and 14mm outlet. We contributed to this study by testing the system with three different diffusers and our result was better than the previous which they achieved 23% humidity level.

Acknowledgments

Firstly, we thank Allah for everything we succeed in. This project was supported by Prince Mohammad Bin Fahd University. We are very thankful to supervisor Dr. Esam Jassm, who guided us to the success of the completion of the project and provided expertise that greatly assisted us in the project. We are also very thankful for our co-advisor Dr. Nader Sawalhi for the continuous support and feedback during the semester. We are also very thankful to all instructors and students who participated in the requirement gathering, their participation extremely assisted us in complete the project.

List of Acronyms (Symbols) used in the report:

P: Pressure.

T: Temperature.

$\boldsymbol{e}$: Parameters at dry gas outlet.

θ: Angle.

D: Diameter.

ϕ: Relative humidity.

$\boldsymbol{P_v}$: Vapor pressure.

P_s: Saturated vapor pressure.

ϕ_{in}: Inlet relative humidity.

ϕ_{out}: Inlet relative humidity.

ω_{in}: Inlet moisture content.

ω_{out}: Exit moisture content.

T_{db}: Dry bulb Temperature.

T_{dew}: Dew point Temperature.

$\eta_{Separation}$: Efficiency of the separation

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Chapter 1: Introduction

1.1 Project Definition

Oil and gas industry- discovering, producing and transporting the natural gas. Throughout these processes, they facing a real challenge with natural gas. Because it is most often mixed with significant quantities of water and others unwanted solid particles. Moreover, these unwanted particles can cause many serious problems during expansion process of natural gas which are corrosion, excessive pressure drop, hydrate, results in a decrement in its heating value such as reduction in gas transmission efficiency. Thus, the need for prevention from this problem becomes critical. However, this issue can be mitigated by separate the water and others unwanted solid particle that presents in natural gas by using the supersonic nozzle. It is good alternative shows good result and really great efficiency to separate the water from natural gas. The purpose of this project is to manufacture new designs of a supersonic nozzle system, in particular, the diffuser portion to test the dehumidifying and separation efficiency of the wet air.

1.2 Project Objectives

Our project objectives are:

1. Solution to dehumidify the natural gas.
2. Investigate new designs of diffuser portion in the supersonic nozzle system in terms of dehumidifying and separation efficiency of the natural gas.
3. Test multiple designs for supersonic nozzle system with different diffusers and compare the result between them in efficiency and separation aspect.
4. To examine different sizes of diffusers and investigate their effect on gas-particle interaction.

1.3 Project Specifications

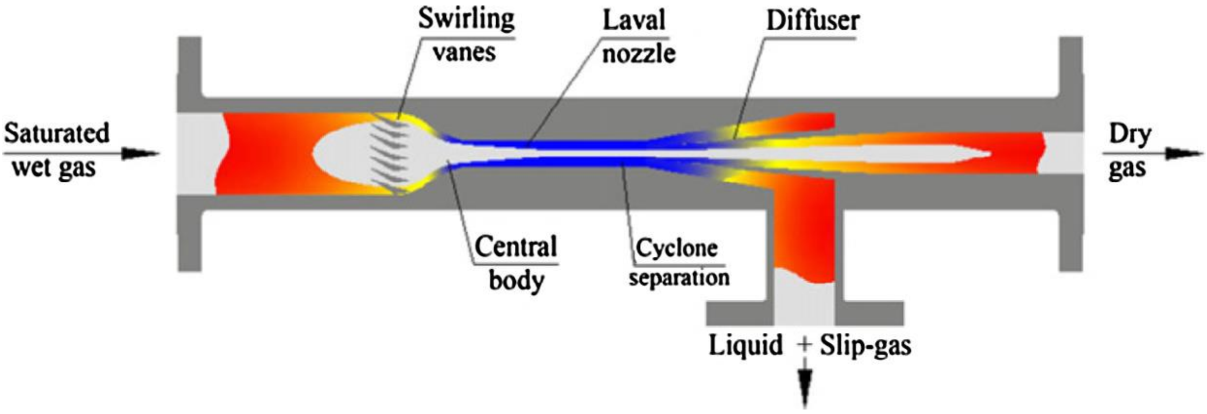

Figure 1.1 (diagram of a supersonic separator.) [1]

Figure 1.2 (real photo of supersonic separator.) [2]

Our system will be consist of two sub-systems:

1. Supersonic nozzle separator system which consists of (Nozzle, separator, and diffuser).
2. Air compressor and pressurized tank system which consists of (220V Air compressor, pressurized tank, pipes, pressure gauge, ball valves and water droplet separator)

1.4 Applications

The supersonic nozzle can be used in:

1. Gas plant to separate water from the gas before processing it.
2. In HVAC system to dehumidify the air.
3. Fixed air compressor.
4. Portable air compressor.
5. Water Dewpoint (Dehydration).
6. Hydrocarbon Dewpoint.
7. Natural Gas Liquids extraction (NGL/LPG).

Chapter 2: Literature Review

2.1 Project background

The supersonic nozzle is a reliable technology for oil and gas industry. Also, it is employed to overcome the deficit of the traditional method, related to gas dynamics thermodynamics and fluid dynamics theory. Previous studies and results showed a positive impact on the separation technology due to simplicity in designing, cost effective in manufacturing, and feasibility in maintenance. However, this project focuses on designing a new supersonic nozzle for moisture removal and quantify the separation efficiency. Humid air is chosen for the study. The working fluid will be circulating in an open loop, which has provision for filtering, metering, and humidifying. A stainless steel supersonic separator will be designed and constructed together with the C-D nozzle system. De-humiliation process performance of humid air using supersonic nozzle will be studied. The impact of diffuser length on the separation efficiency will be quantified.

2.2 Previous Work

It's really important to do research about previous projects and studies to obtain all the information available and related to our project. Therefore, we did thesis researches:

2.2.1 Research:

Dehydration of natural gas using solid desiccants:

Gandhidasan in 2001 [3], Found that natural gas (NG) need to dehydrate and remove water contaminants to meet a water dew point requirement of sales specifications. He design two-tower, solid desiccant dehydrator (as shown in below figure 2.1) using silica gel as one of the most versatile solid desiccants for the dehydration of natural gas have proved to be the most effective liquid desiccants in current use since they have high hygroscopy, low vapor pressure, high boiling points and low solubility in natural gas.

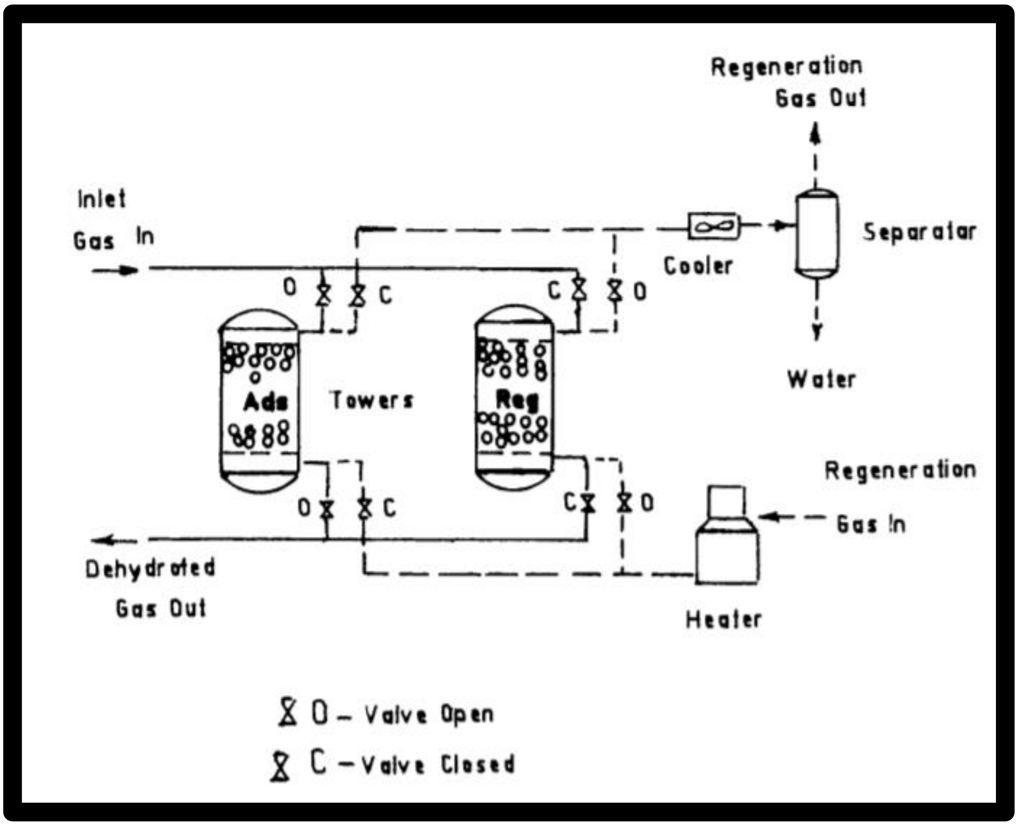

Figure 2.1 (shows the schematic of a two-tower solid desiccant dehydrator.)

2.2.2 Research:

Method of and apparatus for the separation of components of gas mixtures and liquefaction of a gas:

A method proposed in 2003 by Alferov and Betting which is apparatus for the separation and liquefaction of the gas mixtures. [4] Which is "a nozzle having a convergent nozzle portion and a nozzle throat, and a divergent nozzle portion (in the case of supersonic flow), and a working section. Vanes or another mechanism for creating a swirl velocity are connected to the nozzle, to create a strong swirl velocity in the gas fed to the nozzle. In the nozzle, the gas adiabatically expands, gas velocity increases and the gas temperature drops, to promote the condensation of gas with the formation of droplets. The gas then passes through a working section having a wall, whereby further condensation of at least a portion of the gas flow occurs and droplets of condensed gas grow. Centrifugal effects generated by the swirl velocity drive the droplets towards the wall of the working section. Condensed liquid gas droplets are separated from remaining gas in the gaseous state at least adjacent the wall of the working section. The method can be applied to liquefaction of a gas or to the separation of one gas or several gasses from a mixture of gasses." [5] figure 2.2 shows the schematic view of an embodiment of a nozzle that they design. Table 2.1 will describe the name of each part of figure 2.2.

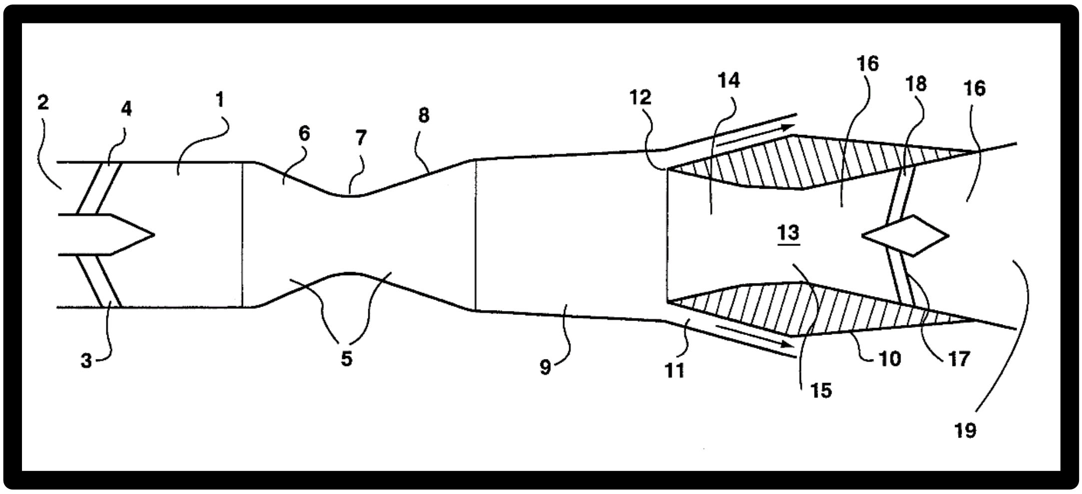

Figure 2.2 (shows the schematic view of an embodiment of a nozzle)

Table 2.1 description the name of parts in figure 2.2

Number#	Description
1	premix chamber
2	Inlet for gas
3	swirl generation device
4	vanes or blades
5	nozzle
6	convergent portion
7	nozzle throat
8	divergent portion
9	working section
10	diffuser body
11	annular slot
12	leading edge
13	central channel
14	supersonic diffuser
15	intermediate section
16	subsonic diffuser
17	means or device
18	comprises vanes or blades
19	outlet

2.2.3 Research:

Twister^{TM}:

According to the research [6], Twister^{TM} is a technology which has been under development for natural gas applications since 1997. It is alternative technology that prevents hydrate problems. Also, eliminating chemicals and associated regeneration systems. Moreover, the first Twister application successfully started-up in December 2003.

- ***How does it work?***

1. A Laval nozzle is used to expand the saturated feed gas to supersonic velocity, which results in a low temperature and pressure. A mist of water and hydrocarbon condensation droplets will form.
2. A wing placed in the supersonic flow regime will generate a high vorticity swirl (up to 300,000g), centrifuging the droplets to the wall.
3. The liquids are spilled from the gas using a cyclone separator.
4. The separated streams are slowed down in separate diffusers, recovering 65-80% of the initial pressure.
5. The liquid stream still contains slip-gas, which will be removed in a compact liquid degassing vessel and recombined with the dry gas stream. (As shown in Figure 2.3)

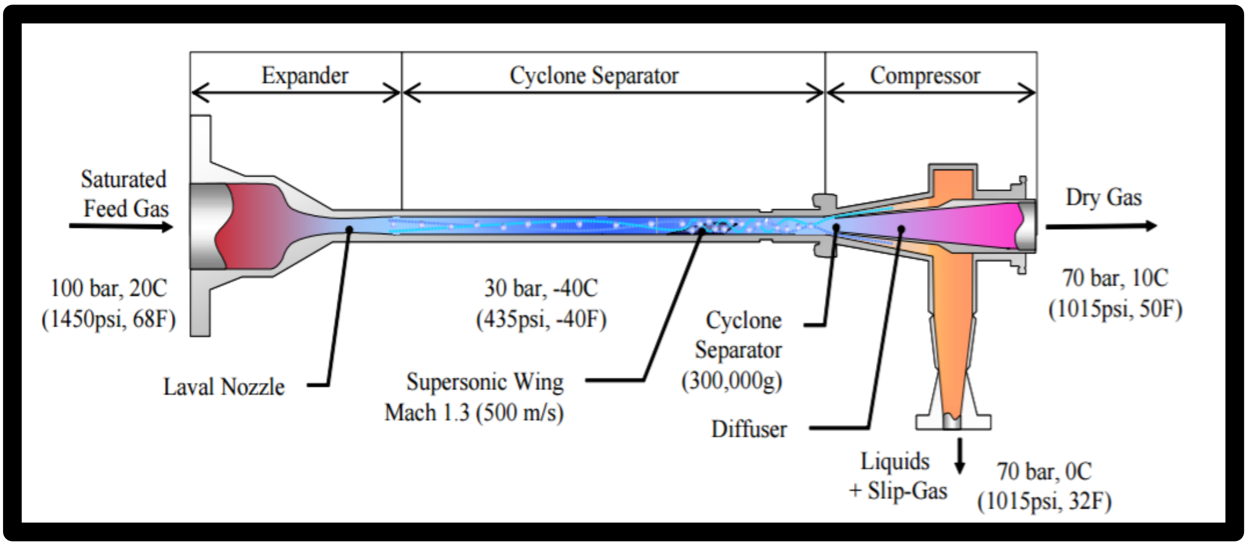

Figure 2.3 (shows cross-section of a Twister tube)

2.2.4 Research:

Dehydration characteristics:

Liu, Z. in 2005 [7]. described a natural gas dehydration unit and presented the corresponding structure and its working principles. The test results for an indoor 3S rig revealed that the pressure loss ratio, the shockwave location, and the fluid flow rate had an immense effect on the overall dehydration characteristics of the entire process.

1- Dehydration performance:

About 10 curves were generated with 5 different tests with a range of P_e. That the dew point of the dry gas outlet decreases monotonically with the increasing of the pressure loss ratio. Which tell us that the pressure loss ratio has very strong influence on the dew point of the dry gas outlet. (As you can see from figure 2.4)

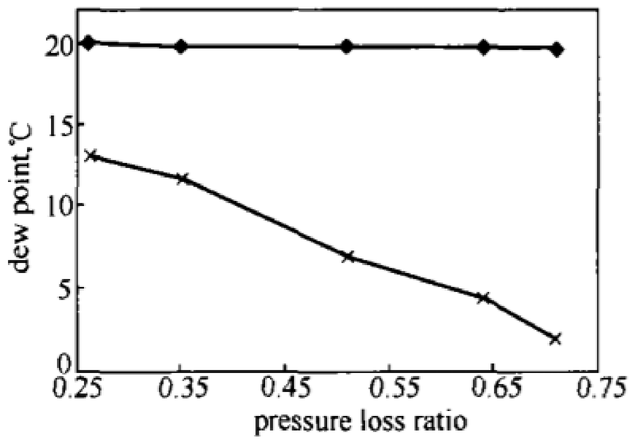

Figure 2.4 (shows the dew point versus pressure loss ratio)

2- Effect on temperature:

Figure 2.5, compares the dry gas outlet temperature with the inlet temperature versus pressure loss ratio. It is seen from figure 2.5, that the outlet temperature is almost recovered completely and nearly independent of the pressure loss ratio.

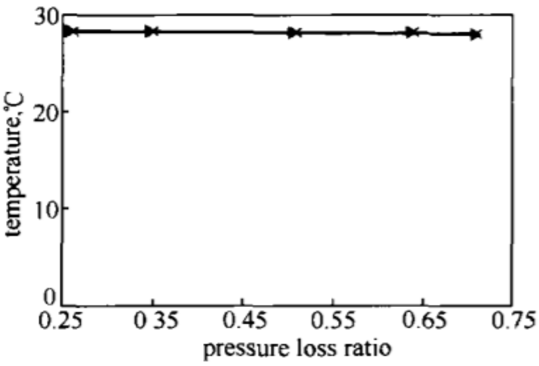

Figure 2.5 (shows the temperature versus pressure loss ratio)

3- Flow Rate:

Figure 2.6 shows that the flow rate through the separator is independent of the pressure loss ratio and therefore it is the critical flow rate of the supersonic swirling separator which also explains why the parameters in Figure 2.5 and 2.6 keep constant in the range of the test.

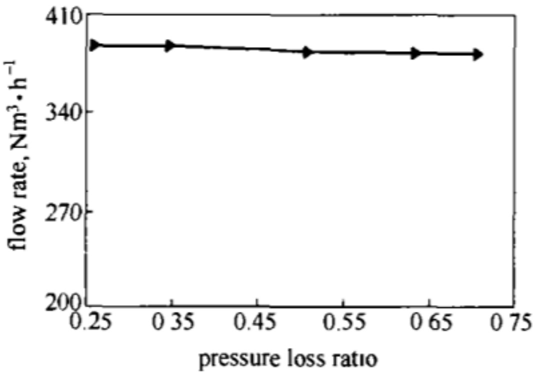

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Figure 2.6 (shows the flow rate versus pressure loss ratio)

It is seen from figure 2.4, 2.5 and 2.6 that the pressure loss ratio is a key factor to that determine the dehydration performance.

2.2.5 Research:

key components of twister separator and hydrocarbon recovery:

Betting and Epsom In 2007 [8], investigated the key components of twister separator and hydrocarbon recovery. They found that in a single compact device of Twister Supersonic Separator combines adiabatic cooling and cyclonic separation.

Adiabatic cooling is an aerodynamically shaped venturi tube— which helps to achieve an isentropic expansion efficiency of 80%. Also, the swirling motion is generated by a vane ring at the entrance of the Laval nozzle. The swirl strength increases strongly, due to contraction in the nozzle, resulting in a centrifugal field of about 500,000 g. The fine, dispersed liquids formed during the adiabatic expansion are separated as a result of the centrifugal forces exerted by the strong swirling flow and removed from the dry flow at a minimum temperature and pressure with a separation efficiency of typically 95%. At the point where liquid/gas separation takes place, the total fluid velocity is around 400 m/s. The remaining kinetic energy in the separated flow streams within the tube is transformed to increased static pressure in the diffuser section. (As shown in Figure 2.7)

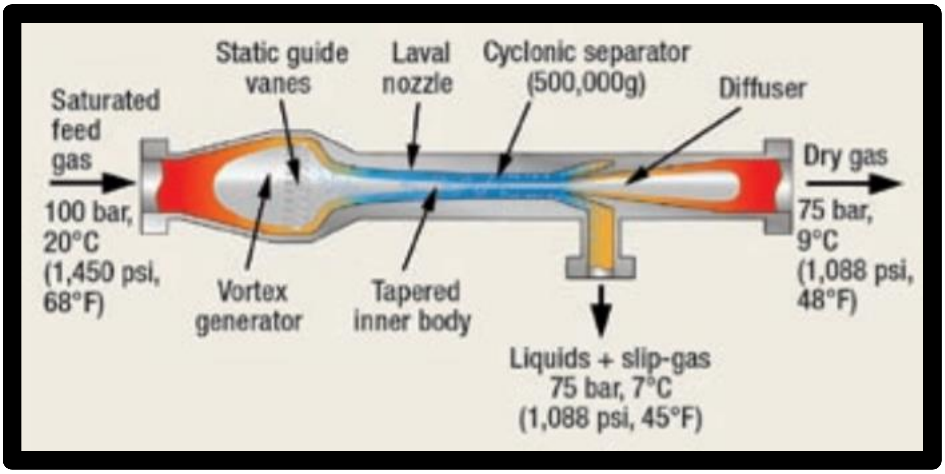

Figure 2.7 (shows cross-section and key components of a Twister Separator)

2.2.6 Research:

consumption of natural gas:

In 2008 Baker and Lokhandwala did research [9] about natural gas (NG) consumption. The total worldwide consumption surpasses 95 trillion scf/year. Also, According to the world by map organization in 2015 show the ranks of countries consumption of natural gas. (As shown in table 2.2)

Table 2.2 show the ranks of countries consumption of natural gas in 2014-2015.

Rank (total)	Country	Total (thousand cubic meters)	per Capita (cubic meters)	Date
1	United States of America	773,200,000	2,405.6	2015 est.
2	Russia	453,300,000	3,181.7	2014 est.
3	China	181,100,000	133.6	2014 est.
4	Iran	170,200,000	2,105.4	2014 est.
5	Japan	131,300,000	1,033.0	2014 est.
6	Canada	116,500,000	3,344.4	2014 est.
7	Saudi Arabia	102,400,000	3,744.6	2014 est.
8	Germany	79,210,000	977.9	2014 est.
9	Mexico	72,770,000	605.0	2014 est.
10	United Kingdom of Great Britain and Northern Ireland	70,450,000	1,105.2	2014 est.

2.2.7 Research:

Nozzle geometry and vorticity:

Jassim et al. (2008) [10], studied the effect of nozzle geometry and vorticity by inserting a constant area channel between the nozzle and diffuser parts of the system. They selected various lengths of such extended constant area regions. Their results emphasized that variation of the channel length would impact the position of the normal shock wave location and the minimum temperature of the system. They also pointed out that gas stream pressure losses are mainly due to inlet swirling flow and vorticity increases very sharply in the vicinity of the normal shock wave. They concluded that "the region just before the shock spot is the main region where fine particles can be separated because of the large vorticity strength".

2.2.8 Research:

the influences of flow friction drag on spontaneous of water vapor flow inside it:

According to the research [11], investigated the influences of flow friction drag on spontaneous condensation of water vapor flow inside supersonic Laval nozzles (As shown in Figure 2.8)

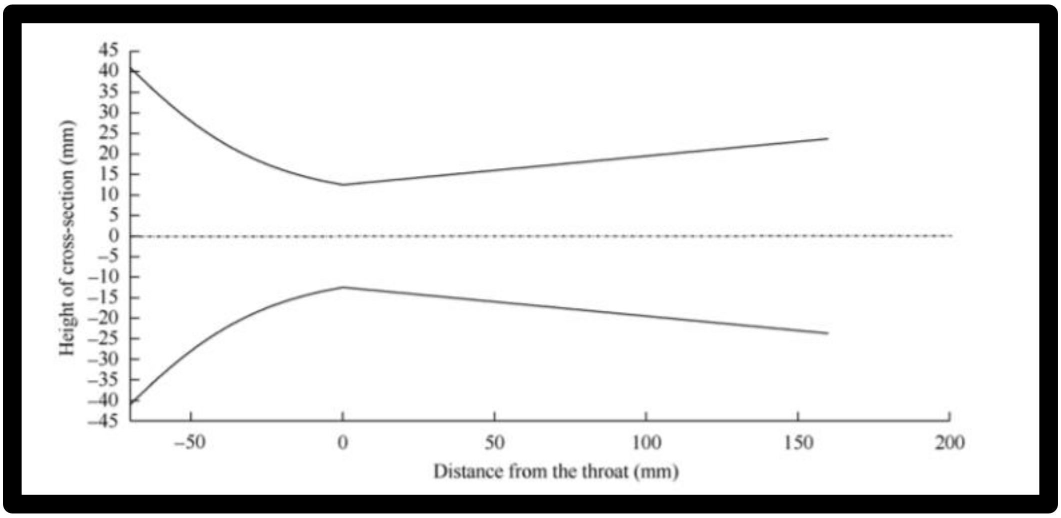

Figure 2.8 (shows Schematic configuration of Laval nozzle)

They did the simulation of several different frictions drags 0, 0.001, 0.005, and 0.01 corresponding to curves A, B, C, and D. (As shown in Figures 2.9 and 2.10)

As you can see from figures 2.9 and 2.10 with the increasing of friction drag, the friction heat increases, making the liquid mass fraction decrease. Moreover, it was found the flow friction has a direct effect on the spontaneous condensation process and therefore it is important to use accurate friction factor predictions when designing this kind of Laval nozzles.

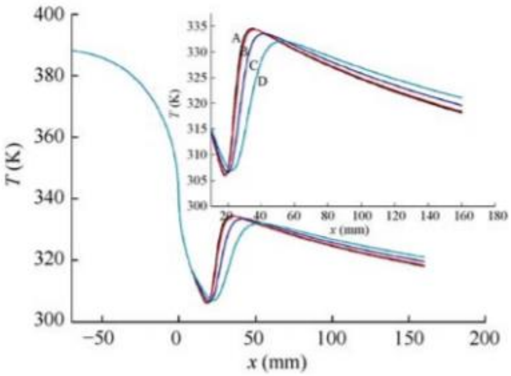

Figure 2.9 (shows temperature distributions along the Laval nozzle axis)

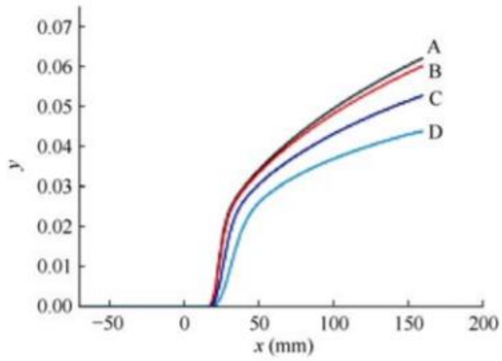

Figure 2.10 (shows liquid mass fraction distributions along the Laval nozzle axis.)

2.2.9 Research:

Dehydration:

According to the first research [12], about selective dehydration of high-pressure natural gas through supersonic nozzles by presented a computational model linked to MATLAB and HYSYS package to predict the effect of different parameters such as the inlet pressure, inlet temperature and flow rate on the behavior of the working fluid.

According to the second research [13], about use (conventional method) for dehydration in the natural gas. The method uses wet gas is contacted with a lean solvent. The water in the gas is absorbed by the lean solvent.

2.2.10 Research:

3S device:

According to the first research [14], founded a technological process for a supersonic separator in 2005 (As shown in Figure 2.11), the benefits from it is that the effectiveness of the 3-S separator, Joule–Thomson valve, and turbo-expander can be compared in extracting C3+ from natural gas.

Applications where 3-S separators used in gas processing plants include:

1. Gas preparation for transportation.
2. LPG extraction, shallow cut, and deep cut.

3. Offshore gas separation and treatment facilities.
4. CO2 extraction, ethane recovery, and LNG applications.

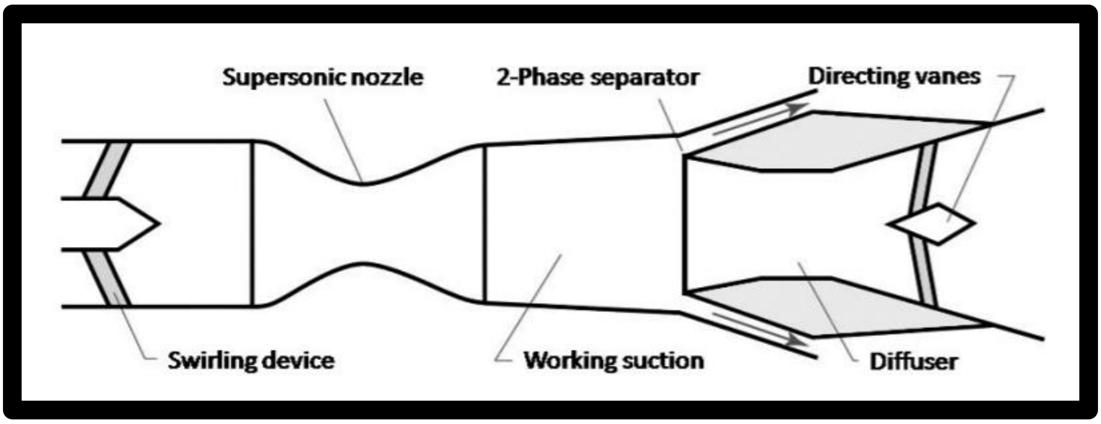

Figure 2.11 (shows the parts of 3-S separator)

According to the second research [15], investigated the non-isentropic performance of supersonic separator. The simulation results clearly indicated that the non-isentropic process causes a premature shock occurrence which inhibits sufficient gas cooling and hinders proper liquid separation. They showed that the diverging nozzle angle and inlet gas velocity have an appreciable effect on the pressure recovery ratio of the 3S unit. Furthermore, they pointed out that the non-isotropicity of the process due to form friction of shock wave had a minor effect on the prediction of shock wave location compared with the non-isotropicity created from skin friction inside the 3S device.

According to the third research [16], presented a rigorous mathematical model combined with the real gas property package to predict the temperature, pressure, velocity and Mach number profiles across the entire 3S unit. An illustrative real case study was also presented to demonstrate the separation mechanism of condensed water and heavy hydrocarbons inside the separator. They showed that more than 84 percent of condensed water and a small fraction of condensed hydrocarbon liquid should be separated from the cooled fluid to meet the pipeline specifications of the natural gas.

According to the fourth research [17], presented a method for primary estimation of the purification efficiency of natural gasses in a 3S unit which depended on their entrance conditions of the gas stream. The results showed that the purification efficiency depends on the temperature, pressure, and Mach number of the gas stream during flow inside 3S unit and it is also a strong function of the liquid phase composition of the gas-liquid mixture. The reported results indicate that the amount of liquid formed increases with decreasing temperature and increasing Mach number of the gas stream inside 3S unit. It was preferable to use separators with Mach number values of 1.4e1.8 at the liquid collection point.

2.2.11 Research:

The latest new design of supersonic:

According to the first research [18], a new design supersonic swirling separator, in which a central body was inserted with the axial and radial distribution of the main parameters of natural gas flow was investigated with RNG K-ε turbulence model to study the effect of the shock waves on the natural gas flow fields. The finding was gas and liquid separation can be effected of non-uniformity of the radial distribution of the gas dynamic parameters significantly. Because of the position of the shock wave determines the distribution of the temperature (As shown in figures 2.12 and 2.13), which has a great influence on the re-evaporation of liquid droplets. In the supersonic separator, the shock wave moves along

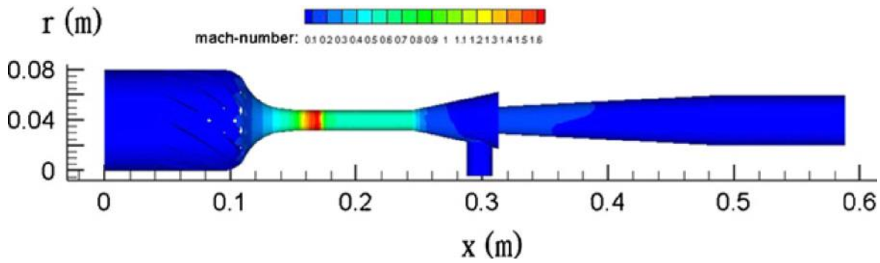

Figure 2.12 (Shockwave in the nozzle)

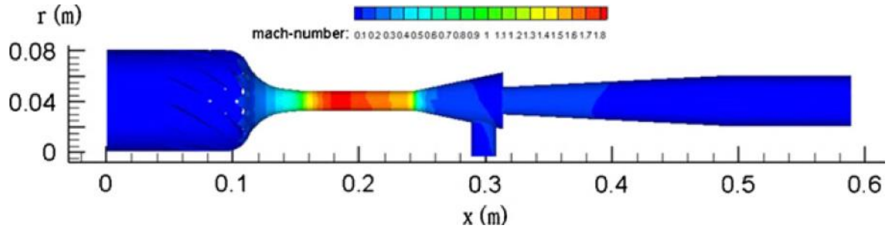

Figure 2.13 (Shockwave in the diffuser)

According to the second research [18], to test the efficiency of three new designed separators with wet air (As shown in figure 2.14). The purpose from this experimental to prove the Discrete Particle Method (DPM) is accurate and stable enough to evaluate the dehydration characteristics of the supersonic swirling separator. The result from this experimental shows that when the length of the cyclone separation section was about 10 times of the diameter of the wall at the throat, the efficiency reached over 95% and the maximum error is about ±6.5%. Also, the results showed that, the centrifugal field of 640 000g (g is the acceleration of gravity) of that the new annular nozzle creates a good natural gas dehydration, because most particles collided with the walls or entered into the liquid collection space directly, while only a few particles escaped together with the gas flow. Table 2.1 will describe the name of each part of figure 2.14.

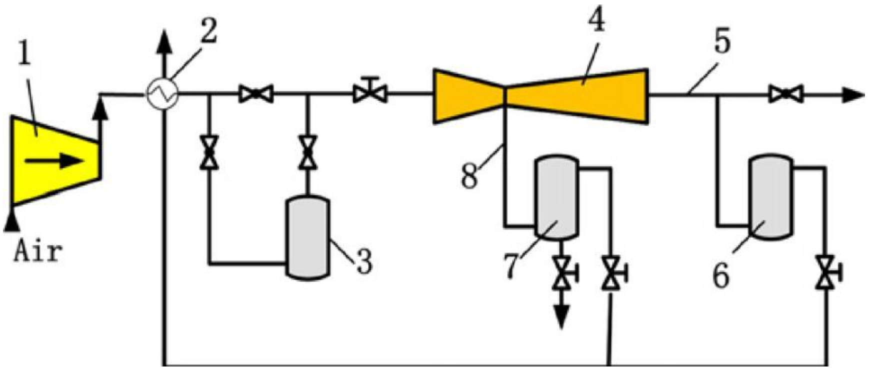

Figure 2.14 (shows the Flowchart of the supersonic swirling separator)

Table 2.3 description the name of parts in figure 2.14

Number#	Name
1	compressor
2	Heat exchanger
3	humidifier
4	the supersonic swirling separator
5	dry gas outlet
6	surge tank
7	gas/liquid separator
8	liquid outlet

2.3 Comparative Study

A program was designed in 2012 by Torres Gonzalez, Michael Netusil, Pavel Dit from Czech Technical University [19] to select the nozzle combination shown in the Figure 2.15 for an interval of inlet volumetric flow. Industrial application of supersonic separation was tested on a production facility offshore Malaysia. They found that the area requirements are lower which makes the supersonic dehydration very suitable for offshore applications. Also, the limiting factor, which is the necessity of stable inlet parameters, can be solved by appropriate battery configuration of nozzles. As it is seen from their calculations shown, if varying inlet volumetric flow in interval <0,8; 1,2> the combination of 4 nozzles will customize with deviation below 4%.

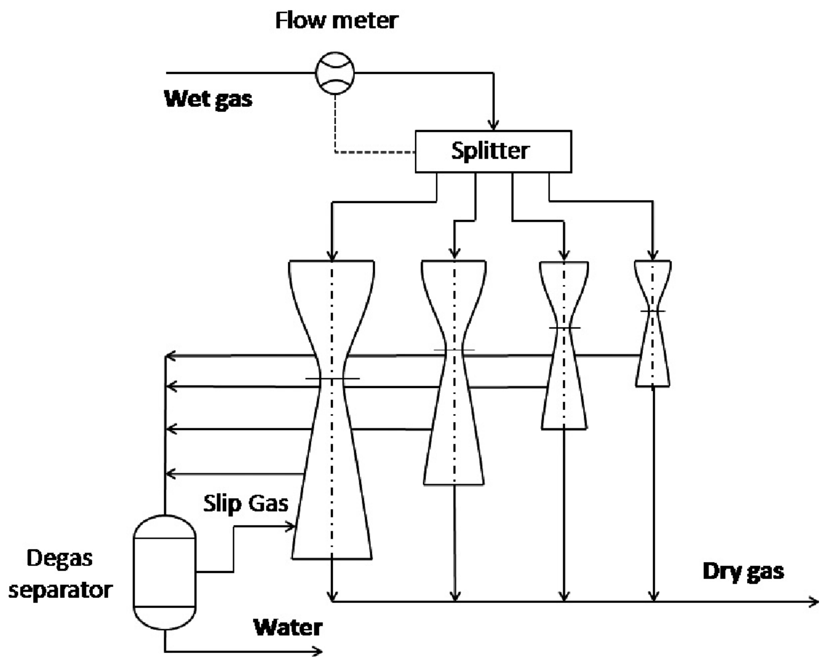

Figure 2.15 (Arrangement of combination nozzles in supersonic for inlet parameters)

As you can see from this project, they use supersonic separation and have the same objective. There are many differences between this project and ours. The main difference is that the combination of 4 nozzles for an interval of inlet volumetric flow. Moreover, we will distinguish their finding and help us in term gathering data.

Chapter 3: System Design

3.1 Design Constraints

3.1.1 General specifications

Supersonic Nozzles technology was used in transport and fighter aircraft. In nowadays the supersonic nozzles enter oil and gas field and industries researchers to reach the highest efficiency and performance. The new Supersonic Nozzles design has many advantages than old technology.

- Smallest size makes it fit to use in industrials.
- Need small space which is good in oil and gas instrumentation.
- Flexibility to choose materials to make the supersonic this mean less cost.

Supersonic Nozzles technology is taking and use the methods related to gas dynamics, thermodynamics and fluid dynamics theory as one of the new gas dehumidification technology. Which is a combination of low-temperature condensation and rotary separation. Experimentally proved that using supersonic nozzle in natural gas purification could save up to 20% compressor power comparing to current conventional equipment.

3.1.2 Constraints and Requirements

3.1.2.1 System:

There are some design constraints we face in order to develop the system. First, during the experiment, It needs critical devices to measure the dehumidification process of moisture fluid and pressure, temperature, humidity ratio, and dew point of the air stream at inlet and exit of the nozzle system. Second, usage natural gas in the experiment to test supersonic nozzles is dangerous on physical and environment. Moreover, to get large basic of data it needs to make three or more different shape supersonic nozzles experiments for each shape are performed which is costly during the experiment. We made three different diffusers to collect data and compare them.

3.1.2.2 Safety:

- Open area
- Safety equipment

3.1.2.2 Economic:

The limit budget for the whole project should not exceed 6500 Riyals Saudi.

3.1.2.3 Time schedule:

- Design the device before 3/05/17.
- Open job order with the manufacturer and start before 04/04/17.
- The device ready for the experiment before 04/10/17.
- Start experimenting before 04/30/17.
- Analyzing the results before 05/14/17.
- Final presentation and final report submission before 05/25/17.

3.2 Design Methodology

In our experimental study of air-dehumidification performance using supersonic nozzle project, our methodology is as followed. First, we will design the particle separation test-stand system. Second, we will design the supersonic nozzle and separator. Third, we will gather the part for the system and try as much to minimize the cost. Fourth, we will assemble the system before manufacturing the supersonic nozzle and separator to check if our system can provide us 100% humid air before connecting the supersonic nozzle and separator. Fifth, we will agree with a workshop to manufacture the supersonic nozzle and separator. Sixth, we will test the system with multiple nozzles and study the data. Finally, we will publish the result.

Equations to be used:

- The Formulation for determining the angle of the diffuser is as following:

  Figure 3.1 shows the schematic drawing of the diffuser layout. In order to get equation 3.3, we have to substitute equation 3.2 into equation 3.1. Using equation 3.4 and figure 3.1, we will calculate the angle of the diffuser.

$$\tan\theta = \frac{D_1}{x} = \frac{D_2}{L+x}$$ Equation 3.1

$$\frac{D_1}{D_2} = \frac{x}{L+x}$$ Equation 3.2

$$\tan\theta = \frac{D_1}{\frac{D1 \times L}{D_2 - D_1}}$$ Sub. Equation 3.2 in 3.1

$$\tan\theta = \frac{D_2 - D_1}{L}$$ Equation 3.3

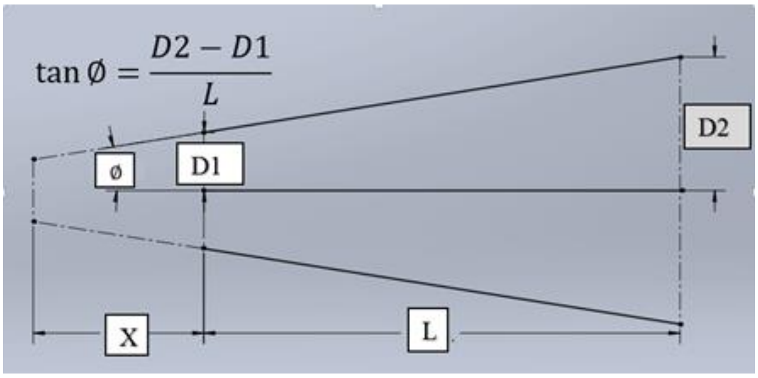

Figure 3.1 (A Schematic Drawing of the Diffuser Layout)

Table 3.1: Description of figure 3.1 symbols

Number#	Name
D1	Inlet Diameter
D2	Exit Diameter
L	Length of the diffuser
θ	Angle of the diffuser
X	Distance from vertix

- The Formulation For determining the efficiency of the separation is as follows:

  Equation 3.5 will be used to find the vapor pressure (P_v) by multiplying the relative humidity with saturated vapor pressure (P_s) which can be gathered from the steam table. To calculate the inlet moisture content (ω_{in}) we have to substitute the vapor pressure (P_v) from equation 3.5 into equation 3.6. To calculate the exit moisture content (ω_{out}) we have to substitute the vapor pressure (P_v) from equation 3.5 into equation 3.7. In order to calculate the separation efficiency of the supersonic nozzle separator system we have to substitute the inlet moisture content (ω_{in}) and the exit moisture content (ω_{out}) from equation 3.6 and 3.7 into equation 3.8

$$\phi = \frac{P_v}{P_s} \qquad \text{Equation 3.4}$$

$$P_v = \phi \times P_s \qquad \text{Equation 3.5}$$

$$\omega_{in} = 0.622 \times \frac{P_{v,in}}{P_{atm} - P_{v,in}} \qquad \text{Equation 3.6}$$

$$\omega_{out} = 0.622 \times \frac{P_{v,out}}{P_{atm} - P_{v,out}} \qquad \text{Equation 3.7}$$

$$\eta_{\text{separation}} = \frac{\omega_{in} - \omega_{out}}{\omega_{in}} \qquad \text{Equation 3.8}$$

3.2.1 The Particle Separation Test-Stand:

The Particle Separation Test-Stand system is the system that we will use to conduct this study. The system consists of two sub-systems:

1. Supersonic nozzle separator system which is responsible for dehumidifying the moist air. The supersonic nozzle separator system is consisting of (Nozzle, separator, and diffuser).

2. Air compressor and pressurized tank system are responsible for providing moist air for conducting the experiment by mixing the pressurized air with water in the pressurized tank. The air compressor and pressurized tank system is consist of (220V Air compressor, pressurized tank, pipes, pressure gauge, ball valves, tees, elbow, check valve and water droplet separator).

Figure 3.2 shows a schematic presentation of the design of the test system. The line in figure 3.2 represents pipes. The air compressor is connected to the pressurized tank inlet. The exit of the pressurized tank is connected to the supersonic nozzle separator system with ball valve between them.

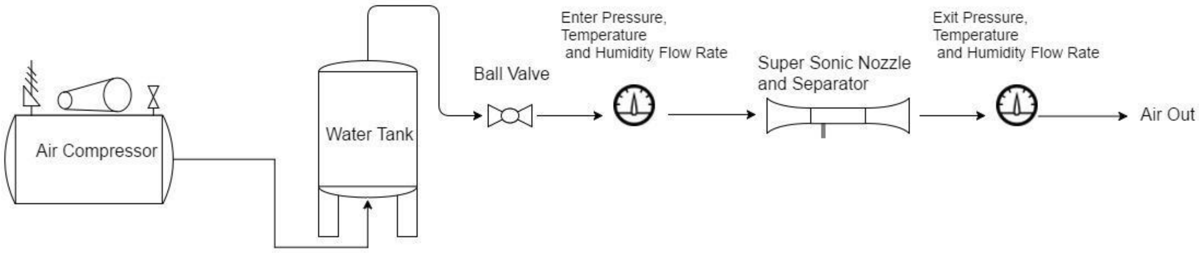

Figure 3.2 (The Particle Separation Test-Stand System)

3.2.2 The Supersonic Nozzle Separator System

The supersonic nozzle separator system is consist of (Nozzle, separator, and diffuser). The nozzle and separator will remain the same as the previous study we will change only the diffusers. In order to find the impact of the diffuser length on the separation level and efficiency we will test three different diffusers with the same inlet and exit diameter (2 mm, 14 mm) and different length (50 mm, 70 mm, 90 mm) and compare the result. All diffusers inlet and exit diameter are the same. Figure 3.3 shows a 2D drawing of the 50 mm length with an angle of 6.86°. Figure 3.4 shows a 2D drawing of the 70 mm length with an angle of 4.90°. Figure 3.5 shows a 2D drawing of the 90 mm length with an angle of 3.81°. Figure 3.6 shows a 2D drawing of the separator that we got from the previous group. Figure 3.7 shows a 2D drawing of the nozzle that we got from the previous group. Figure 3.8 shows a 2D assembled and exploded view drawing of the supersonic nozzles separator system. Table 3.1 will describe the name of each part of figure 3.8.

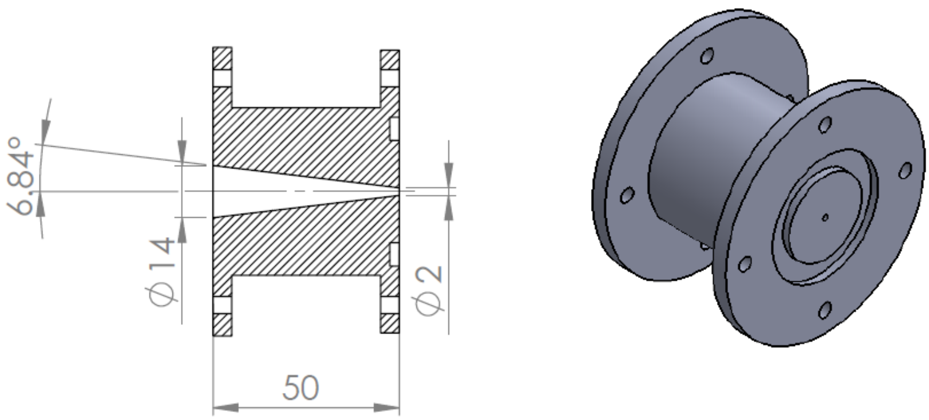

Figure 3.3 (Shows a 2D Drawing of The 50mm Diffuser)

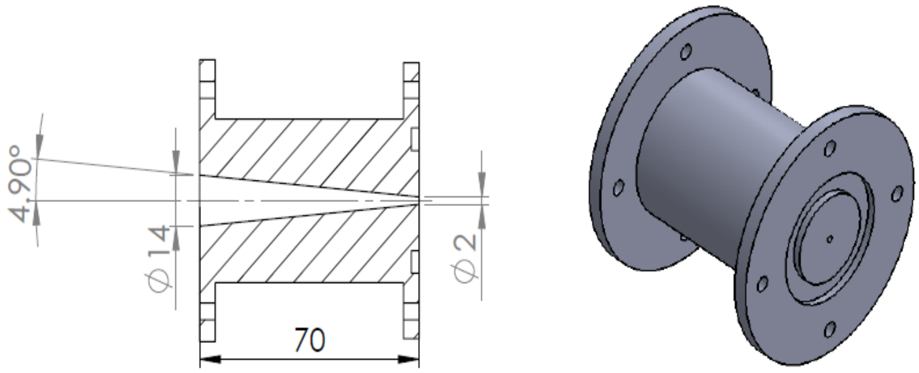

Figure 3.4 (Shows a 2D Drawing of The 70mm Diffuser)

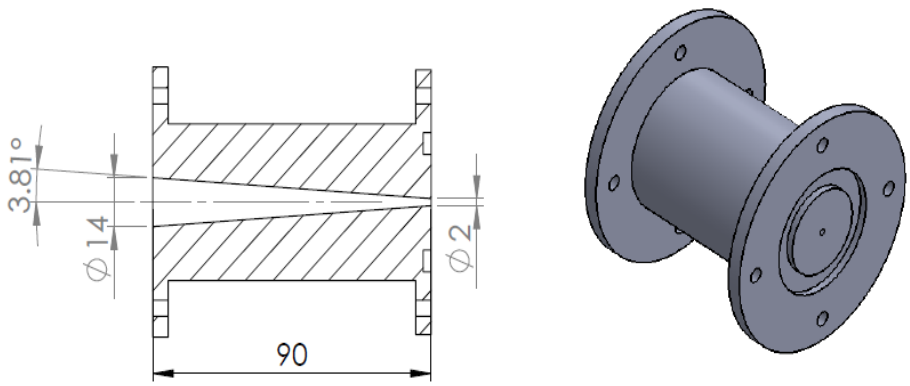

Figure 3.5 (Shows a 2D Drawing of The 90mm Diffuser)

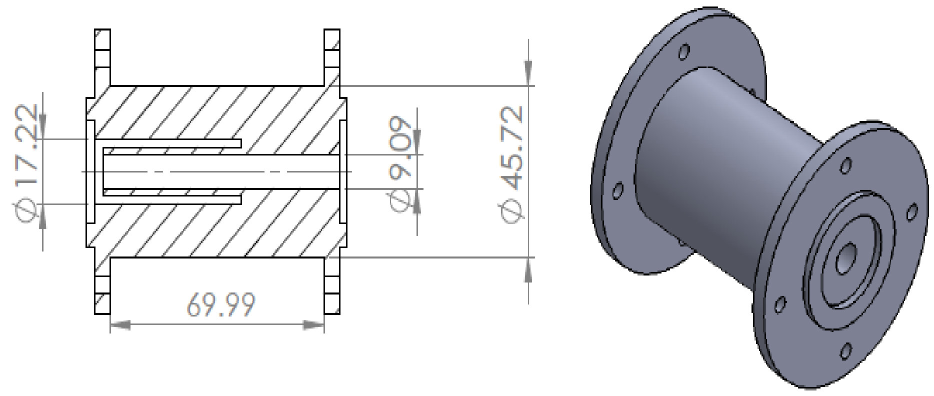

Figure 3.6 (Shows a 2D Drawing of The Separator)

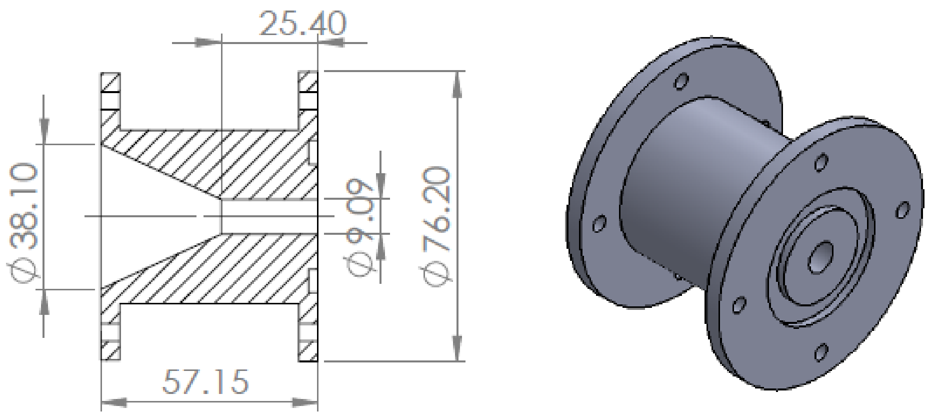

Figure 3.7 (Shows a 2D Drawing of The nozzle)

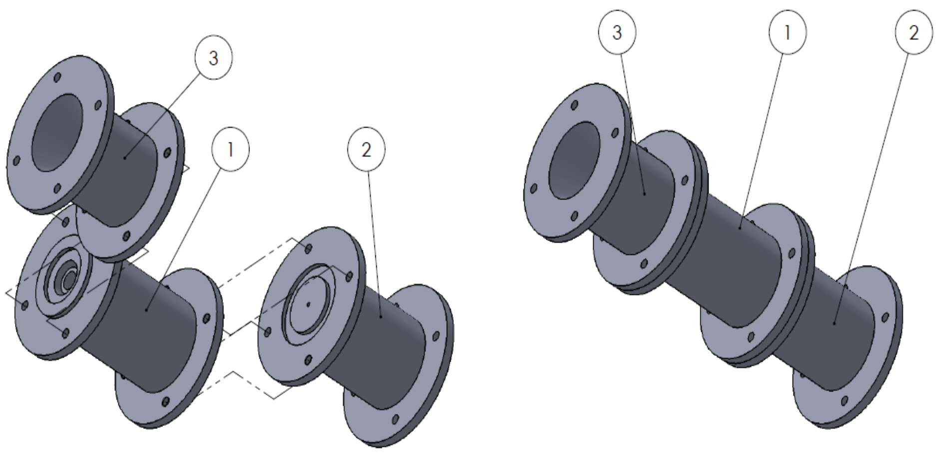

Figure 3.8 (Shows a 2D Assembled and Exploded View Drawing of The Supersonic Nozzles Separator System)

Table 3.2 description the name of parts in figure 3.8

Number#	Name
1	Separator
2	Nozzle
3	Diffuser

3.3 Product Subsystems and Components

3.3.1 Nozzle

It is the first component of the supersonic nozzle separator system we use in this project. The nozzle is used to drop the temperature and pressure of the inlet and increase the velocity.

3.3.2 Supersonic Separator

The supersonic separator is an important component that is located between the nozzle and diffuser. Also, it has a small valve used as the drain of the water. The water leaves the drain because of the removing of humidity by the centrifugal force. The type of the valve is ball valve and it is always open to allow the water to go outside and to make sure the device is work probably.

3.3.3 Diffuser

The diffuser is the last part of the supersonic nozzle separator system. It is very important for return back the pressure and temperature to the original. We will make three diffusers with different length in order to find better efficiency and compare the result.

3.3.4 Air Compressor

Air compressor (As shown in figure 3.9) is a device that converts power using an electric motor into potential energy stored in pressurized air.it is a supplier of air that goes directly to the water tank through the tubes. Figure 3.9 shows the compressor we used.

Figure 3.9 (Shows The Compressor We Used)

3.3.5 Pressure Tank

A pressure tank (As shown in figure 3.10) is a tank for storing pressurized air which is used for many application. In our project, we modified the tank by drilling a hole in the top so we can fill it with water so the pressurized air enters from the bottom and mix with the water and then exit from the top as humid air. Figure 3.10 shows the pressurized tank we used.

Figure 3.10 (The Pressurized Tank We Used)

3.3.6 Tubes and Pressure Gages

We used in our project stainless steel tube. It connects all the system component together such as air compressor with the pressurized tank and the pressurized tank with the supersonic nozzle separator system and. Also, we have air pressure gages which are located after the compressor (As shown in figure 3.11). Figure 3.11 shows the pressure gauge we used.

Figure 3.11 (The pressure Gauge We Used)

3.4 Implementation

In our experimental study of air-dehumidification performance using supersonic nozzle project, our system assembly is as followed. First, we will connect the air compressor output to the inlet of the pressurized tank by a pipe. Second, we will fill the pressurized tank with water in order the air from the compressor carries water particle and become humidified air. Third, we will run the pipe out of the pressurized tank to water filters to remove any dust and imperfection then to the ball valve. Fourth, we will run the pipe out of the filter to the inlet gauges then into the supersonic nozzle and separator. Finally, we will run the pipe out of the supersonic nozzle and separator to the exit gauges and then to the outlet.

To complete the experiment, first, we will fill the pressurized tank with water. Then, we will start the compressor and wait for the pressure to build up. Next, we will open the outlet ball valve and measure the outlet humidity level if it above 95%, we could proceed.

After that, we will connect the supersonic nozzle separator system to the pressurized tank and air compressor system. Then, we will collect the inlet and exit data. Finally, we will repeat the process for each diffuser.

To verify our system work before collecting the data, we will run the system without the supersonic nozzle separator system, in order to check for leaks and we will open the outlet ball valve and measure the outlet humidity level if it above 95% and no leak observed, then we will proceed.

In order, the manufacturer manufactures the three diffusers. First of all, the manufacturer has to cut a round steel billet into three pieces with different length sizes (50mm, 70mm, 90mm). Next, using lathe machine the manufacturer have to machine the flange shape and the fitting holes. Then, using CNC lathe machine (Computer Numerical Control) the manufacturer have to machine the inside cone shape. Finally, the manufacturer has to polish the diffuser using sandpaper.

Chapter 4: System Testing and Analysis

4.1 Subsystem 1 (Supersonic Nozzle Separator System)

The objective of the testing is to ensure that our supersonic nozzle separator system work in a perfect way. In order our system pass the test before experimenting we did the following:

- First, we applied Teflon tape on all the fitting and threads to prevent any leaks.
- Second, we applied rubber gasket between the nozzle, separator, and diffuser to prevent any leaks.
- Third, we fasten the nuts and bolts very well to prevent any leaks.
- Finally, we tested our supersonic nozzle separator system function by connect it to the air compressor and pressurized tank system and checked for any leak.

To perform the experiment:

- First, we fill the air pressurized tank with water and turn on the air compressor and wait for the pressure to build up.
- Second, we open the outlet valve and measure the humidity level from the air compressor and pressurized tank system it should give us from 95% to 100% in order to conduct the experiment.
- Third, we connect the supersonic nozzle separator system to the air compressor and pressurized tank system.
- Finally, we open the outlet valve and measure the humidity level (As shown in Figure 4.1) from the supersonic nozzle separator system with three different diffusers and note the results as shown in Table 4.1.

Figure 4.1 (Shows the way of measuring the humidity level)

Table 4.1: Testing of The Supersonic Nozzle separator System

Test Number	Objectives	Results	Status
1	Assembly and test the system	One of the gaskets was leaking	Fail
2	Test the system after fixing the leak	The system is leak free and ready	Successful
3	Conducting the experiment with 50mm diffuser	The exit air humidity level is 18%	Successful
4	Conducting the experiment with 70mm diffuser	The exit air humidity level is 17%	Successful
5	Conducting the experiment with 90mm diffuser	The exit air humidity level is 17%	Successful

4.2 Subsystem 2 (Air Compressor and Pressurized Tank System)

The aim of the second system is to prepare the test condition which is from 95% to 100% humid air. In order our system pass the test before experimenting we did the following:

- First, we tighten all the pipes and applied Teflon tape on all the fitting and threads to prevent any leaks.
- Second, we checked the air compressor oil level.
- Third, we fill the air pressurized tank with water.
- Fourth, we run the air compressor and pressurized tank system and check for any leaks.
- Finally, we open the outlet valve and measure the humidity level from the air compressor and pressurized tank system it should give us from 95% to 100% in order to conduct the experiment as shown in Table 4.2.

To perform the experiment:

- First, we fill the air pressurized tank with water and turn on the air compressor and wait for the pressure to build up.
- Second, we open the outlet valve and measure the humidity level from the air compressor and pressurized tank system it should give us from 95% to 100% in order to conduct the experiment.

- Third, we connect the supersonic nozzle separator system to the air compressor and pressurized tank system.
- Finally, we open the outlet valve and measure the humidity level (As shown in Figure 4.1) from the supersonic nozzle separator system with three different diffusers and note the results.

Table 4.2: Testing of The Air Compressor and pressurized tank system

Test Number	Objectives	Results	Status
1	Assembly and test the system	The exit air humidity level is below 95%	Fail
2	Test the system after adding more water	We found multiple leaks in the system	Partially Successful
3	Test the system after fixing all the leaks	The exit air humidity level is above 95%	Successful

4.3 Overall Results, Analysis and Discussion

In this project, firstly we tested the system, in the beginning, the test fails because there are some problems such as leaking and low humidity level because of the low level of water of the air compressor and pressurized tank system. After that, we solved the problems that happen in air compressor and pressurized tank system by tightening all the pipes and applied Teflon tape on all the fitting and threads to prevent any leaks, adding rubber gasket between the nozzle, separator, and diffuser to prevent any leaks and fill the air pressurized tank with water.

Our experiments goals are to dehumidify the humid air below 25% and get separation efficiency above 75%.

We need three resources to conduct the experiment which is as listed below:

- 220V power source for the air compressor.
- Fresh water for the pressurized tank.
- Humidity level sensors to measure the result.

The procedure for conducting the experiment is as follows:

- First, we will fill the pressurized tank with water.
- Second, we will start the compressor and wait for the pressure to build up.
- Third, we will open the outlet ball valve and measure the outlet humidity level if it above 95% we will proceed. (As shown in Figure 4.2)
- Fourth, we will connect the supersonic nozzle separator system to the pressurized tank and air compressor system.
- Fifth, we will collect the exit data. (As shown in Figure 4.3, Figure 4.4, and Figure 4.5)
- Finally, we will repeat the process for each diffuser.

Figure 4.2 (Shows the humidity result before connecting the supersonic nozzle separator system)

Figure 4.3 (Shows the humidity result of the supersonic nozzle separator system with 50mm diffuser)

Figure 4.4 (Shows the humidity result of the supersonic nozzle separator system with 70mm diffuser)

Figure 4.5 (Shows the humidity result of the supersonic nozzle separator system with 90mm diffuser)

Results of 50 mm Diffuser :

Inlet calculation:

$\phi = 99\%$, $T_{db} = 33.1℃$, From Steam table: $P_s = 5.035\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.99 \times 5.035 = 4.985\ kPa$$

Using Equation 5.6:

$$\omega_{in} = 0.622 \times \frac{P_{v,in}}{P_{atm} - P_{v,in}}$$

$$\omega_{in} = 0.622 \times \frac{4.985}{101.3 - 4.985} = 32.19 \times 10^{-3}\ kg/kg - air$$

Exit calculation:

$\phi = 18\%$, $T_{db} = 38.7℃$, From Steam table: $P_s = 6.886\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.18 \times 6.886 = 1.239\ kPa$$

Using Equation 5.7:

$$\omega_{out} = 0.622 \times \frac{P_{v,out}}{P_{atm} - P_{v,out}}$$

$$\omega_{out} = 0.622 \times \frac{1.239}{101.3 - 1.239} = 7.701 \times 10^{-3}\ kg/kg - air$$

Separation efficiency calculation:

Using Equation 5.6:

$$\eta_{\text{separation}} = \frac{\omega_{in} - \omega_{out}}{\omega_{in}}$$

$$\eta_{\text{separation}} = \frac{32.19 \times 10^{-3} - 7.701 \times 10^{-3}}{32.19 \times 10^{-3}} = 76.076\%$$

Results of 70 mm Diffuser :

Inlet calculation:

$\phi = 99\%$, $T_{db} = 33.1°C$, From Steam table: $P_s = 5.035\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.99 \times 5.035 = 4.985\ kPa$$

Using Equation 5.6:

$$\omega_{in} = 0.622 \times \frac{P_{v,in}}{P_{atm} - P_{v,in}}$$

$$\omega_{in} = 0.622 \times \frac{4.985}{101.3 - 4.985} = 32.19 \times 10^{-3}\ kg/kg - air$$

Exit calculation:

$\phi = 17\%$, $T_{db} = 39.1°C$, From Steam table: $P_s = 7.036\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.17 \times 7.036 = 1.196\ kPa$$

Using Equation 5.7:

$$\omega_{out} = 0.622 \times \frac{P_{v,out}}{P_{atm} - P_{v,out}}$$

$$\omega_{out} = 0.622 \times \frac{1.196}{101.3 - 1.196} = 7.731 \times 10^{-3}\ kg/kg - air$$

Separation efficiency calculation:

Using Equation 5.6:

$$\eta_{\text{separation}} = \frac{\omega_{in} - \omega_{out}}{\omega_{in}}$$

$$\eta_{\text{separation}} = \frac{32.19 \times 10^{-3} - 7.731 \times 10^{-3}}{32.19 \times 10^{-3}} = 75.983\%$$

Results of 90 mm Diffuser :

Inlet calculation:

$\phi = 99\%$, $T_{db} = 33.1°\mathrm{C}$, From Steam table: $P_s = 5.035\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.99 \times 5.035 = 4.985\ kPa$$

Using Equation 5.6:

$$\omega_{in} = 0.622 \times \frac{P_{v,in}}{P_{atm} - P_{v,in}}$$

$$\omega_{in} = 0.622 \times \frac{4.985}{101.3 - 4.985} = 32.19 \times 10^{-3}\ kg/kg - air$$

Exit calculation:

$\phi = 17\%$, $T_{db} = 38.1°\mathrm{C}$, From Steam table: $P_s = 6.661\ kPa$, $P_{atm} = 101.3\ kPa$

Using Equation 5.5:

$$P_v = \phi \times P_s$$

$$P_v = 0.17 \times 6.661 = 1.132\ kPa$$

Using Equation 5.7:

$$\omega_{out} = 0.622 \times \frac{P_{v,out}}{P_{atm} - P_{v,out}}$$

$$\omega_{out} = 0.622 \times \frac{1.132}{101.3 - 1.132} = 7.029 \times 10^{-3}\ kg/kg - air$$

Separation efficiency calculation:

Using Equation 5.6:

$$\eta_{\text{separation}} = \frac{\omega_{in} - \omega_{out}}{\omega_{in}}$$

$$\eta_{\text{separation}} = \frac{32.19 \times 10^{-3} - 7.029 \times 10^{-3}}{32.19 \times 10^{-3}} = 78.164\%$$

By analyzing each diffuser result, we found out the following:

For 50mm diffuser:

- The inlet humidity level is about 99%.
- The system reduce the humidity level to 18%
- The separation efficiency was 76.076%.

For 70mm diffuser:

- The inlet humidity level is about 99%.
- The system reduce the humidity level to 17%
- The separation efficiency was 75.893%.

For 90mm diffuser:

- The inlet humidity level is about 99%.
- The system reduce the humidity level to 17%
- The separation efficiency was 78.164%.

In conclusion, when we used the 50mm diffuser the system reduce the humidity level to 18% and the separation efficiency was 76.076%. Also, when we used the 70mm diffuser the system reduce the humidity level to 17% and the separation efficiency was 75.893%. In addition, when we used the 90mm diffuser the system reduce the humidity level to 17% and the separation efficiency was 78.164%. Furthermore, We got the best performance from using the 90mm diffuser. Finally, we reached our goal which is below 25% humidity level and above 75% separation efficiency.

Chapter 5: Project Management

5.1 Project Plan

Table 5.1: This table shows the project tasks with its duration and to what member was assigned to.

Task	Duration	Assigned to	Start date	Finish date
Forming group	6d	Mohammed	02/05/17	02/12/17
First meeting with the co-adviser	1d	All	02/12/17	02/12/17
Choosing project	6d	All	02/12/17	02/19/17
Gantt chart	5d	Abdulrahem and Omar	02/18/17	02/22/17
First meeting with the adviser	1d	All	02/19/17	02/19/17
Milestone 2	10d	Abdulrahem and Omar	02/20/17	03/05/17
Design the device	7d	All	02/23/17	03/05/17
Milestone 3	17d	All	03/02/17	03/26/17
Second Meeting with the adviser	1d	All	03/05/17	03/05/17
Search for proper manufacturer	3d	All	03/06/17	03/08/17
Negotiate with the manufacturer	1d	Abdulrahem and Omar	03/12/17	03/12/17
Set the budget	1d	Mohammed and Omar	03/13/17	03/13/17
Gathering the money	1d	Mohammed and Omar	03/14/17	03/14/17

Open job order with the manufacturer and start	15d	Abdulrahem	03/15/17	04/04/17
Search for proper parts and equipment	3d	All	03/15/17	03/19/17
Third Meeting with the adviser	1d	All	03/19/17	03/19/17
Select and order the parts and equipment	3d	Abdulrahem and Omar	03/19/17	03/21/17
Receive the parts and equipment	7d	Abdulrahem	03/22/17	03/30/17
Start assembly	7d	All	03/31/17	04/09/17
Fourth Meeting with the adviser	1d	All	04/02/17	04/02/17
Milestone 4	6d	Abdulrahem and Omar	04/09/17	04/16/17
The device ready for experiment	1d	All	04/10/17	04/10/17
Start experimenting	7d	All	04/11/17	04/19/17
Fifth Meeting with the adviser	1d	All	04/16/17	04/16/17
Milestone 5	15d	Abdulrahem and Omar	04/17/17	05/07/17
Sixth Meeting with the adviser	1d	All	04/30/17	04/30/17
Seventh Meeting with the adviser	1d	All	05/14/17	05/14/17

Finalizing the presentation and report	13d	Abdulrahem and Omar	05/08/17	05/24/17
Last Meeting with the adviser	1d	All	05/21/17	05/21/17
Final presentation and final report submission	1d	All	05/25/17	05/25/17

5.2 Contribution of Team Members

1. Mohammed Alhindi: (20%)

   Forming group, Choosing project, Design the device,Milestone 3, Search for the proper manufacturer, Set the budget, Gathering the money, Search for proper parts and equipment, Start assembly, The device ready for the experiment, Start experimenting.

2. Bassam Al-Baqawi: (15%)

   Design the device, Milestone 3, Search for the proper manufacturer, Search for proper parts and equipment, Start assembly, The device ready for the experiment, Start experimenting.

3. Abdullah Aleisini: (15%)

   Design the device, Milestone 3, Search for the proper manufacturer, Search for proper parts and equipment, Start assembly.The device ready for the experiment, Start experimenting.

4. Omar Alnafisi: (25%)

   Choosing project, Gantt chart, Milestone 2, Design the device, Milestone 3, Search for proper manufacturer, Negotiate with the manufacturer, Set the budget, Gathering the money, Search for proper parts and equipment, Select and order the parts and equipment, Start assembly, The device ready for experiment, Milestone 4, Start experimenting, Milestone 5.

5. Abdulrahem Alboainain: (25%)

Choosing project, Gantt chart, Milestone 2, Design the device, Milestone 3, Search for proper manufacturer, Negotiate with the manufacturer, Open job order with the manufacturer and start, Search for proper parts and equipment, Select and order the parts and equipment, Receive the parts and equipment, Start assembly, The device ready for experiment, Milestone 4, Start experimenting, Milestone 5.

5.3 Project Execution Monitoring

- Weekly meeting with the advisor.
- Monthly meeting with the co-advisor.
- Contacting the advisor all the time by phone and WhatsApp application to ask him any question or give him an update.
- Giving the leader update and feedback every day.
- Weekly meeting with the team.
- Meeting with the advisor to verify the working condition of the system before start experimenting.

5.4 Challenges and Decision Making

Throughout this project, there were some difficulties while doing the project:

1- Problems regard the place to store the system.
2- Problems with team members.
3- Problems with other courses' projects.
4- Problems regard delays in manufacturing our parts.
5- Problems with equipment/components.
6- Problems with changing the final exams date.

5.4.1 Problems regard the place to store the system.

We faced a problem with the place to store the system and the difficulties of transferring the system.

We solved this problem by storing the system in one of our member's house and regarding the transferring, we rented a Dyna truck.

5.4.2 Problems with team members.

We faced some problems with some members because there was a lack of communication and there was a confusion of the assigned task and some of the team members is part time student so they were busy because of their job.

We solved the lack in communication problem by discussing the problem with each other to improve the communication and we made a WhatsApp group. We solved the confusion of the assigned task problem by explaining the task probably and repeated much time. We solved the part-time member's problem sometimes by splitting their work and assigned to others and sometimes by helping them during the weekend to finish their tasks.

5.4.3 Problems with other courses' projects.

Other courses' projects disrupted us that we could not focus on one project.

We solved this problem by better time management and planning dates that Suit all team members.

5.4.4 Problems regard delays in manufacturing our parts.

We faced some problems with the manufacturer because he was asking us to delay the delivery date after our agreement and start manufacturing.

We solved this problem by not accepting the delay and pushing the manufacturer to deliver our parts in time with the best quality.

5.4.5 Problems with equipment/components.

We faced some problems with one of the equipment specifically the pressurized tank. The pressurized tank was not functioning well because it was 4 years old and very rusty from inside.

We solved this problem by buying a new one and it was a very difficult task because the pressurized tank model was very old.

5.4.6 Problems with changing the final exams date.

We face problems regard changing the date of the final that disrupted us on an aspect of dates and scheduling of project.

We solved this by rescheduling and change the date in plan tasks and by better time management.

5.5 Project Bill of Materials and Budget

Table 5.2: This table shows a bill of materials with the cost of each of them and the total cost of the project.

	Cost in Saudi Riyal
Transferring the system	250 SR
3D printing prototype of three diffusers	475 SR
Manufacturing three diffusers	4000 SR
New Pressurized tank	350 SR
Different expenses	225 SR
Total	5300 SR

Our estimation budget was 6500 SR, however, we managed to spend 1200 less than our estimated budget.

Chapter 6: Project Analysis

6.1 Life-long Learning

From this project, we learned many things and we gained some experience, knowledge, and skills. Working in a group with different members taught us how to get benefits from using many skills, for example, time management, proper communication, teamwork, problem-solving, responsibility, organization, negotiation, troubleshooting and conflict management. Moreover, we acquired our references from internet, library, articles, experts in this field. Also while working in this project we learned the different function of the nozzle and diffuser. In addition, we learned how to found leaking pipes and how to fix them. Furthermore, we learned new manufacturing process which is CNC (Computer Numerical Control) lathe machine which this method is different than the typical method we know. Also, we get the chance to apply the knowledge that we know from university and experience. In addition, we learned about our humidity level measuring device and how it work. Furthermore, we developed our skill in working with SolidWork, for example, sketching complex shapes. Finally, we discovered 3D printing technology and learned about more which that helped us with verifying our design dimensions.

6.2 Impact of Engineering Solutions

Natural gas processing applications are demanding reliability equipment for processing. A supersonic nozzle is alternative that has been introduced to meet such demands. Supersonic nozzles have proven to be reliable to use as an alternative particle separation devices for its ability to perform the process more efficiently. Moreover, supersonic technology has many advantages compared with other technologies such as simplicity in designing, cost effective in manufacturing, feasibility in maintenance. Decrease space requirements, increase portability, Decrease handling, decrease installation costs, decrease costs of operating, cause no harmful impact on environmental, and make no demand for routine maintenance.

Dehumidification process is an important and difficult part of gas processing plant especially offshore plants as it avoids several important problems during the gas processing. By improving our system to reach below 1% humidity level and implement it in every gas plant we will help the environment by cutting the use of chemical treatment and filters that used to dehumidify the gas which those are very harmful to the environment because of the waste and mass production of them. In addition, Our system will help the economy by lowering the gas plant and power plant expenses. Furthermore, our system is totally recyclable, green to use and the manufacturing process for it is simple. In addition, using pre-filters, filters, and chemical treatment are very expensive because filters have to be changed with time. By using a chemical treatment, plants waste will be more and more which that will harm the environment.

6.3 Contemporary Issues Addressed

Oil and gas industry- discovering, producing and transporting the natural gas. Throughout these processes, they facing a real challenge with natural gas. It is well known that natural gas flow most often mixed with significant quantities of water and others unwanted solid particles. Moreover, these unwanted particles can cause many serious problems during expansion process of natural gas which are corrosion, excessive pressure drop, hydrate, the decrease of its heating value and the reduction in gas transmission efficiency.

However, all gas planet in Gulf Cooperation Council Country, in particular, Saudi Arabia face a huge challenge with dehumidifying the gas for in gas plants. Saudi Aramco dehumidifies the gas by using pre-filters, filters and chemical treatment which this process is very expensive because filters have to be changed with time and the chemical have to be imported from outside the kingdom. By using a chemical treatment, plants waste will be more and more which that harm the environment. Most Gulf Cooperation Council Country power is from gas operated power plant which that make the dehumidifying process big challenge must be dealt with.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

In conclusion, this project is about finding a solution to dehumidify the natural gas by a supersonic nozzle which is reliable technology to employ as well as to overcome the deficit of the traditional method such as using pre-filters, filters, and chemical treatment. Moreover, the main focus of this project was designing three diffusers with different length. We achieved in our study 19% humidity level with 50mm and 17% with 70mm and 90mm diffusers with 2mm inlet and 14 mm outlet. We contributed to this study by testing the system with three different diffusers and our result was better than the previous which they achieved 23% humidity level.

We have learned many things and gained some experience, knowledge, and skills. Working in a group with different members taught us how to get benefits from using many skills, for example, time management, proper communication, teamwork, problem-solving, responsibility, organization, negotiation, troubleshooting, and conflict management. Also while working in this project we learned the differences in function between the nozzle and the diffuser. The most important thing that we learned is getting the chance to apply the knowledge that we gained from university and experience.

7.2 Future Recommendations

In order to carry on with our study, we recommend to experiment with a different diffuser, nozzle and separator dimensions and try to get result lower below 15% humidity level. In addition, we recommend trying a different material, for example, Teflon and plastic. Furthermore, we recommend experimenting with a diffuser with a length more than 90mm. In addition, we recommend changing the pressurized tank in the test stand system to a proper one that is not containing a balloon inside it. Finally, we recommend to connect two supersonic nozzle separator system together and try experimenting with it (As shown in figure 7.1).

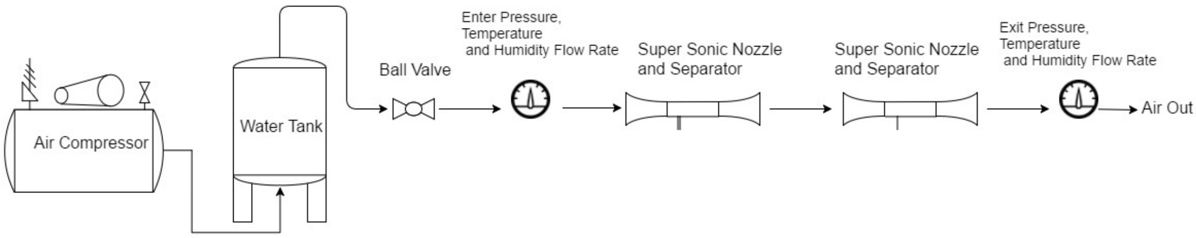

Figure 7.1 (Shows The Particle Separation Test-Stand System with Two Supersonic Nozzle Separator System)

8. References

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Appendix A: Progress Report

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	Spring	ACADEMIC YEAR:	2017
PROJECT TITLE	Design and Experimental Study on air-Dehumidification Performance using Supersonic Nozzle		
SUPERVISORS	Dr. Esam Jassim		

Month 1: February

ID Number	Member Name
201100253	Mohammed Alhindi
201102784	Omar Alnafisi
201201386	Abdulrahem Alboainain
201102679	Abdullah Aleisini
201000974	Bassam Al-Baqawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Forming Group	Mohammed Alhindi	100%	The report
2	Gantt chart	Abdulrahem Alboainain Omar Alnafisi	100%	The report
3	Working on Ch1&2 (report)	Omar Alnafisi Abdulrahem Alboainain	100%	The report
4	Design the device	All	100%	The report

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Search for proper manufacturer	Abdullah Aleisini Bassam Al-Baqawi

		Abdulrahem Alboainain
2	**Negotiate with manufacturer**	**Omar Alnafisi** **Abdulrahem Alboainain**
3	**Working on Ch3 (report)**	**All**
4	**Set the budget**	**Mohammed Alhindi** **Omar Alnafisi**
5	**Gathering the money**	**Mohammed Alhindi** **Omar Alnafisi**

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f:
An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d:
An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects

d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Mohammed Alhindi**	4	4	4	4
2	**Omar Alnafisi**	4	4	4	4
3	**Abdulrahem Alboainain**	4	4	4	4
4	**Abdullah Aleisini**	4	4	4	4
5	**Bassam Al-Baqawi**	4	4	4	4

Comments on individual members

Name	Comments
Mohammed Alhindi	No comment
Omar Alnafisi	No comment
Abdulrahem Alboainain	No comment
Abdullah Aleisini	No comment
Bassam Al-Baqawi	No comment

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	Spring	ACADEMIC YEAR:	2017
PROJECT TITLE	Design and Experimental Study on air-Dehumidification Performance using Supersonic Nozzle		
SUPERVISORS	Dr. Esam Jassim		

Month 2: March

ID Number	Member Name
201100253	Mohammed Alhindi
201102784	Omar Alnafisi
201201386	Abdulrahem Alboainain
201102679	Abdullah Aleisini
201000974	Bassam Al-Baqawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Search for proper manufacturer	Abdullah Aleisini Bassam Al-Baqawi Abdulrahem Alboainain	100%	The report
2	Negotiate with manufacturer	Omar Alnafisi Abdulrahem Alboainain	100%	The report
3	Working on Ch3 (report)	All	100%	The report
4	Set the budget	Mohammed Alhindi Omar Alnafisi	100%	The report
5	Gathering the money	Mohammed Alhindi Omar Alnafisi	100%	The report

List the tasks planned for the month of April and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned

1	**Open job order with manufacturer and start**	**Abdulrahem Alboainain**
2	**Search for proper parts and equipment**	**All**
3	**Receive the parts and equipment**	**Abdulrahem Alboainain**
4	**Working on (report)**	**Omar Alnafisi** **Abdulrahem Alboainain**
5	**Start assembly**	**All**

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest
Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks

d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Mohammed Alhindi**	4	4	4	4
2	**Omar Alnafisi**	4	4	4	4
3	**Abdulrahem Alboainain**	4	4	4	4
4	**Abdullah Aleisini**	4	4	4	4
5	**Bassam Al-Baqawi**	4	4	4	4

Comments on individual members

Name	Comments
Mohammed Alhindi	No comment
Omar Alnafisi	No comment
Abdulrahem Alboainain	No comment
Abdullah Aleisini	No comment
Bassam Al-Baqawi	No comment

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2017
PROJECT TITLE	Design and Experimental Study on air-Dehumidification Performance using Supersonic Nozzle		
SUPERVISORS	Dr. Esam Jassim		

Month 3: April

ID Number	Member Name
201100253	Mohammed Alhindi
201102784	Omar Alnafisi
201201386	Abdulrahem Alboainain
201102679	Abdullah Aleisini
201000974	Bassam Al-Baqawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Open job order with manufacturer and start	Abdulrahem Alboainain	100%	The report
2	Search for proper parts and equipment	All	100%	The report
3	Receive the parts and equipment	Abdulrahem Alboainain	100%	The report
4	Working on (report)	Omar Alnafisi Abdulrahem Alboainain	100%	The report
5	Start assembly	All	100%	The report

List the tasks planned for the month of May and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	The device ready for experiment	All
2	Start experiment	All

3	**Working on (report)**	**Omar Alnafisi** **Abdulrahem Alboainain**
4	**Finalizing the presentation and report**	**Abdulrahem Alboainain** **Omar Alnafisi**

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest
Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Mohammed Alhindi**	4	4	4	4
2	**Omar Alnafisi**	4	4	4	4
3	**Abdulrahem Alboainain**	4	4	4	4
4	**Abdullah Aleisini**	4	4	4	4
5	**Bassam Al-Baqawi**	4	4	4	4

Comments on individual members

Name	Comments
Mohammed Alhindi	No comment
Omar Alnafisi	No comment
Abdulrahem Alboainain	No comment
Abdullah Aleisini	No comment
Bassam Al-Baqawi	No comment

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	Spring	ACADEMIC YEAR:	2017
PROJECT TITLE	Design and Experimental Study on air-Dehumidification Performance using Supersonic Nozzle		
SUPERVISORS	Dr. Esam Jassim		

Month 4: May

ID Number	Member Name
201100253	Mohammed Alhindi
201102784	Omar Alnafisi
201201386	Abdulrahem Alboainain
201102679	Abdullah Aleisini
201000974	Bassam Al-Baqawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	**The device ready for experiment**	All	100%	The report
2	**Start experiment**	All	100%	The report
3	**Working on (report)**	Omar Alnafisi Abdulrahem Alboainain	100%	The report
4	**Finalizing the presentation and report**	Abdulrahem Alboainain Omar Alnafisi	100%	The report

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f1. Demonstrate an understanding of engineering professional and ethical	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with	Shows limited and less than adequate understanding of engineering professional and ethical	Demonstrates satisfactory an understanding of engineering professional and ethical standards in	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety

standards in dealing with public safety and interest	public safety and interest	standards in dealing with public safety and interest	dealing with public safety and interest	and interest
Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Mohammed Alhindi**	4	4	4	4
2	**Omar Alnafisi**	4	4	4	4
3	**Abdulrahem Alboainain**	4	4	4	4
4	**Abdullah Aleisini**	4	4	4	4
5	**Bassam Al-Baqawi**	4	4	4	4

Comments on individual members

Name	Comments
Mohammed Alhindi	No comments

Omar Alnafisi	No comments
Abdulrahem Alboainain	No comments
Abdullah Aleisini	No comments
Bassam Al-Baqawi	No comments

Appendix B: Bill of Materials

Table B.1: This table shows a bill of materials with the cost of each of them and the total cost of the project.

	Cost in Saudi Riyal
Transferring the system	250 SR
3D printing prototype of three diffusers	475 SR
Manufacturing three diffusers	4000 SR
New Pressurized tank	350 SR
Different expenses	225 SR
Total	5300 SR

Appendix C: Datasheets

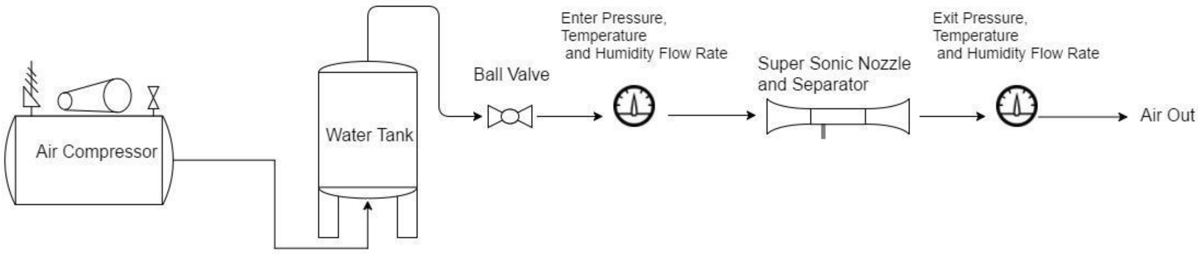


Figure C.1 (The Particle Separation Test-Stand System)

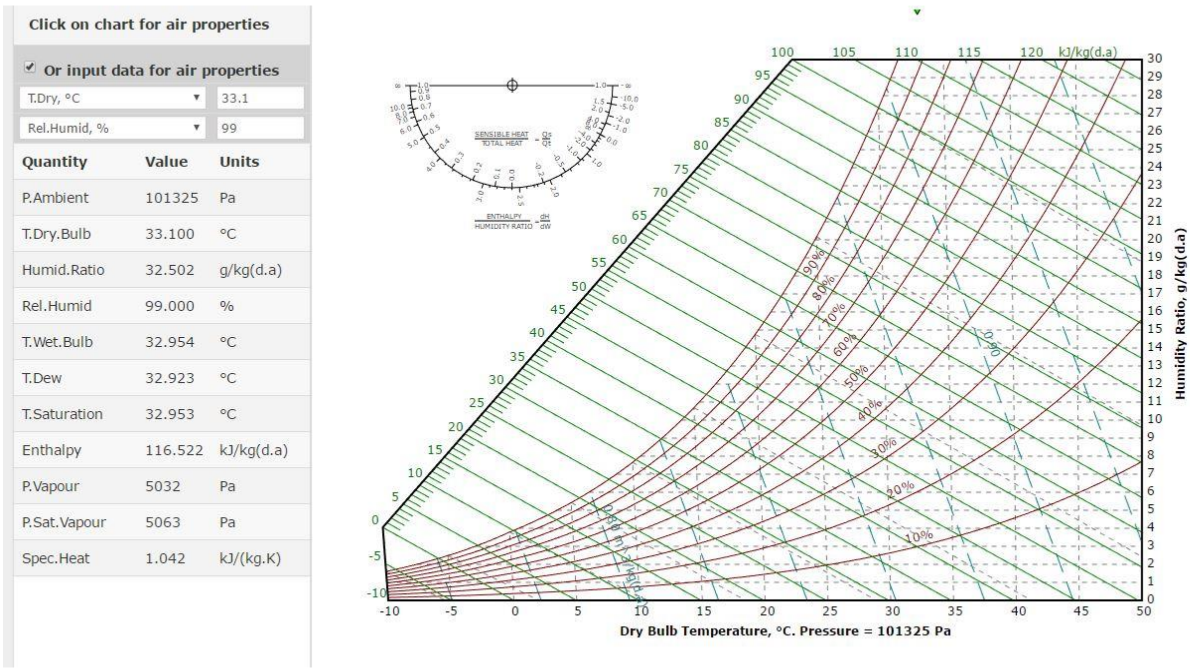
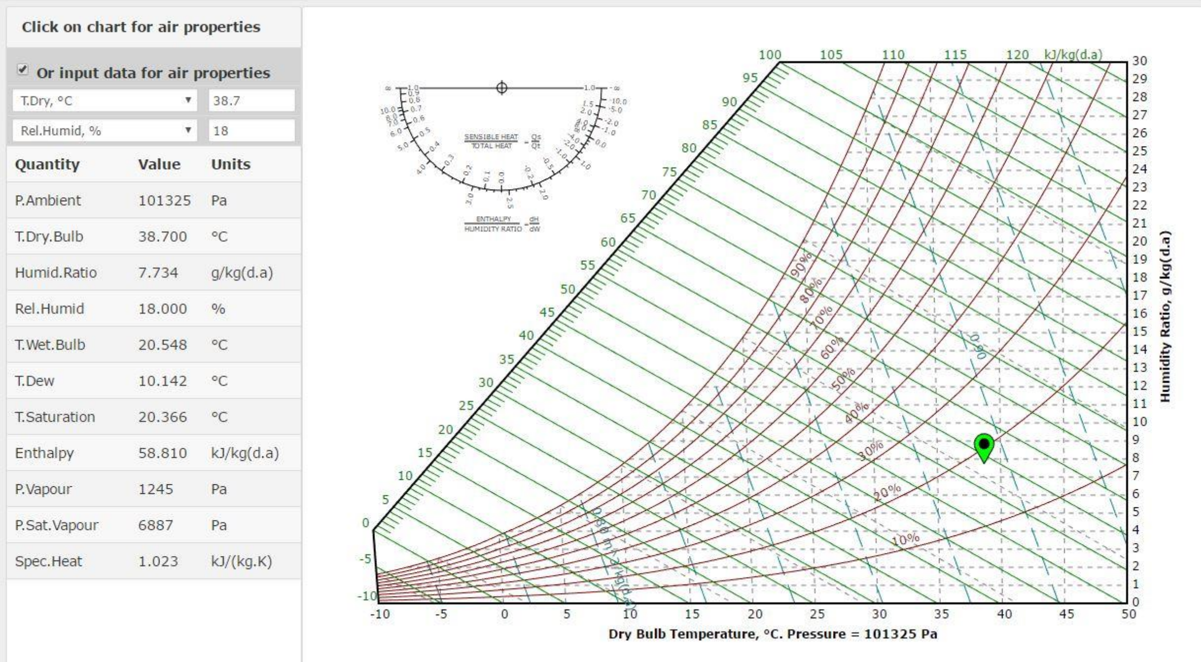
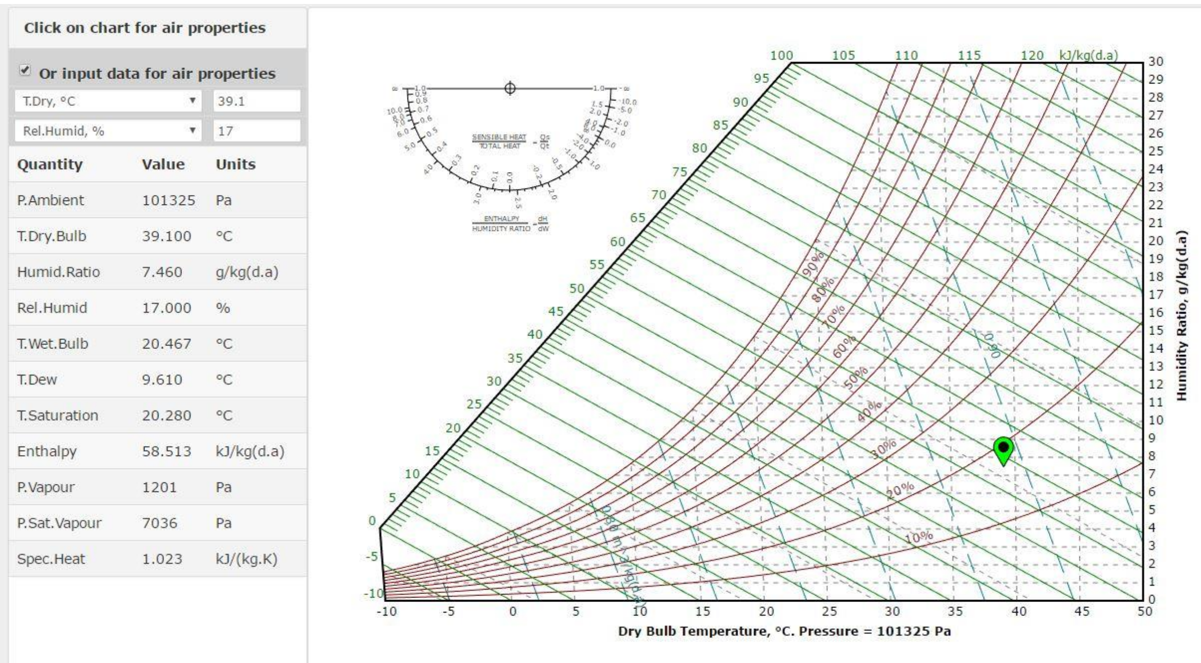


Figure C.2 (Result Values in Psychrometric Chart of Testing Before Adding The System)



Quantity	Value	Units
P.Ambient	101325	Pa
T.Dry.Bulb	38.700	°C
Humid.Ratio	7.734	g/kg(d.a)
Rel.Humid	18.000	%
T.Wet.Bulb	20.548	°C
T.Dew	10.142	°C
T.Saturation	20.366	°C
Enthalpy	58.810	kJ/kg(d.a)
P.Vapour	1245	Pa
P.Sat.Vapour	6887	Pa
Spec.Heat	1.023	kJ/(kg.K)

Figure C.3 (Result Values in Psychrometric Chart of Testing After Adding The System with 50mm Diffuser)



Quantity	Value	Units
P.Ambient	101325	Pa
T.Dry.Bulb	39.100	°C
Humid.Ratio	7.460	g/kg(d.a)
Rel.Humid	17.000	%
T.Wet.Bulb	20.467	°C
T.Dew	9.610	°C
T.Saturation	20.280	°C
Enthalpy	58.513	kJ/kg(d.a)
P.Vapour	1201	Pa
P.Sat.Vapour	7036	Pa
Spec.Heat	1.023	kJ/(kg.K)

Figure C.4 (Result Values in Psychrometric Chart of Testing After Adding The System with 70mm Diffuser)

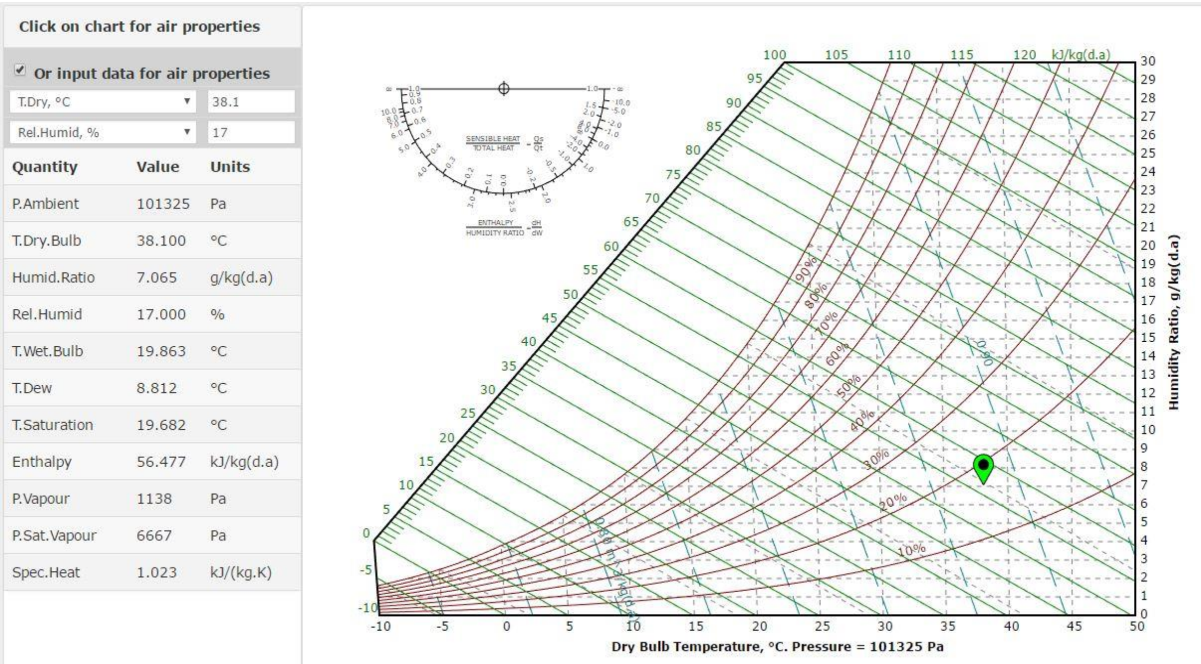
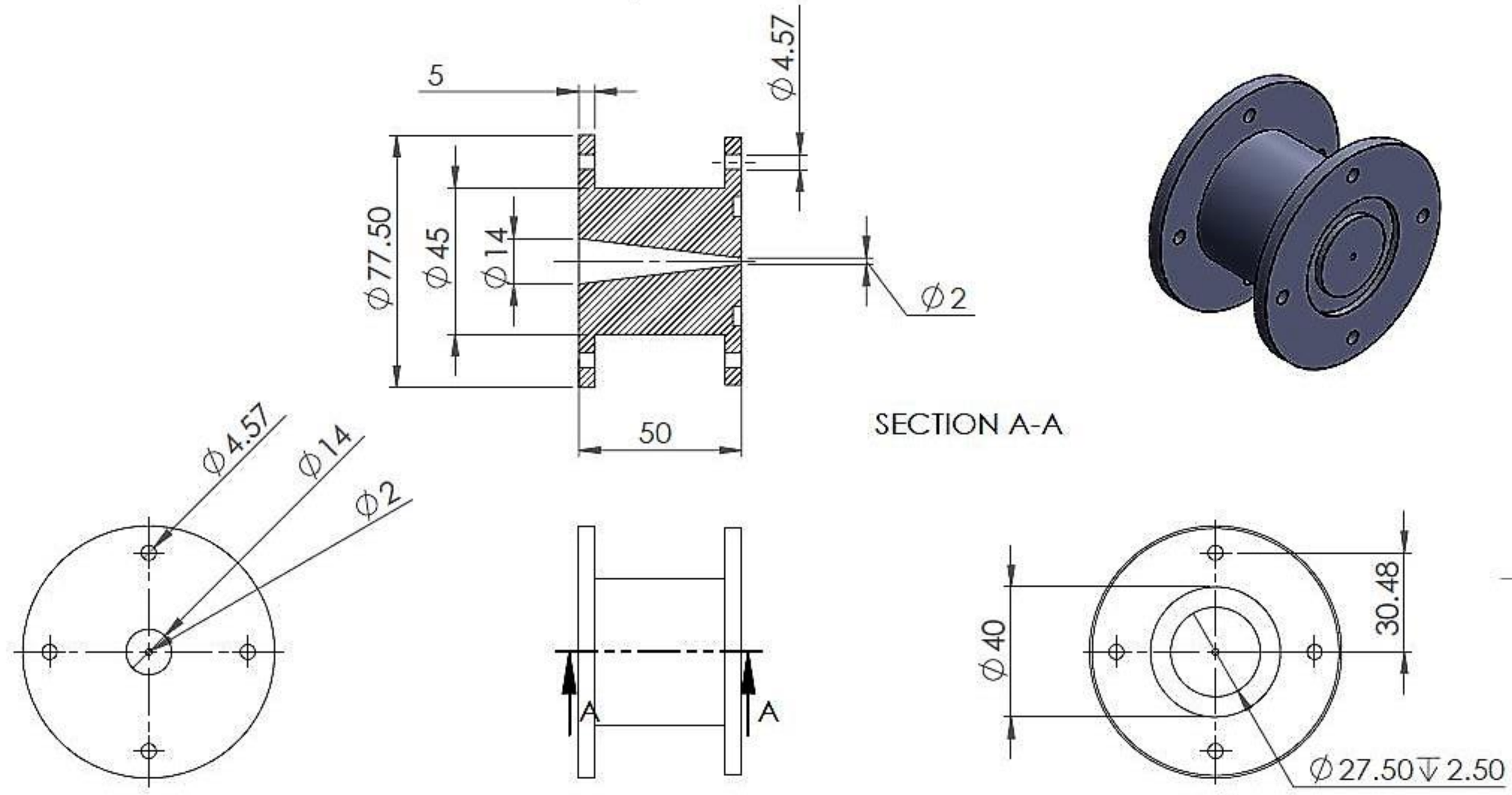


Figure C.5 (Result Values in Psychrometric Chart of Testing After Adding The System with 90mm Diffuser)



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	NAME	SIGNATURE	DATE
DRAWN	Abdulrahem		23/2/2017
CHK'D	Omar		23/2/2017
APPV'D	Dr. Essam		24/2/2017
MFG	Khawater		15/3/2017
Q.A			

MATERIAL:

WEIGHT:

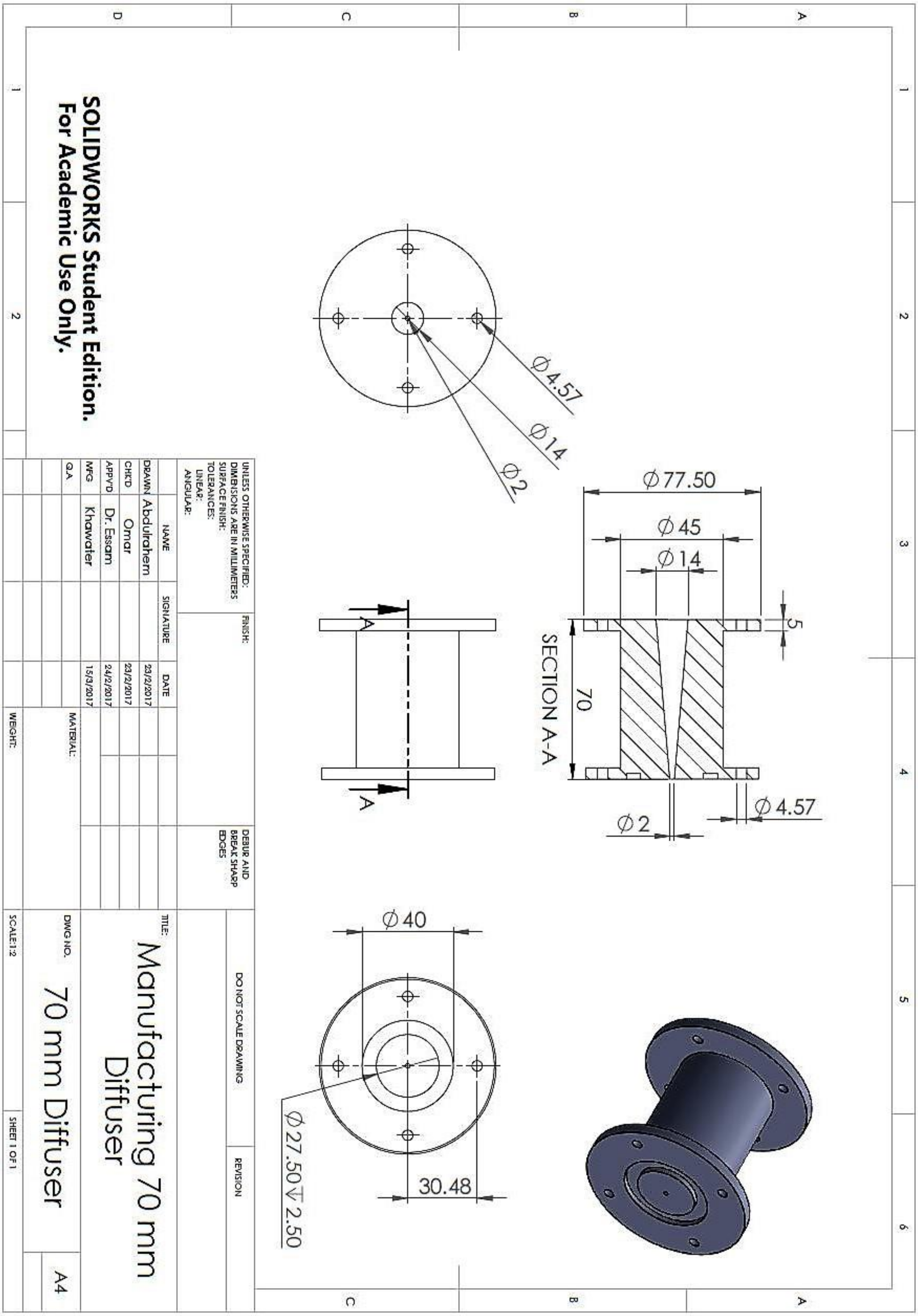
TITLE: Manufacturing 50 mm Diffuser

DWG NO. 50 mm Diffuser

A4

SCALE:1:2

SHEET 1 OF 1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NAME
SIGNATURE
DATE
DRAWN Abdulrahem 23/2/2017
CHK'D Omar 23/2/2017
APPV'D Dr. Essam 24/2/2017
MFG Khawater 15/3/2017
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70 mm Diffuser
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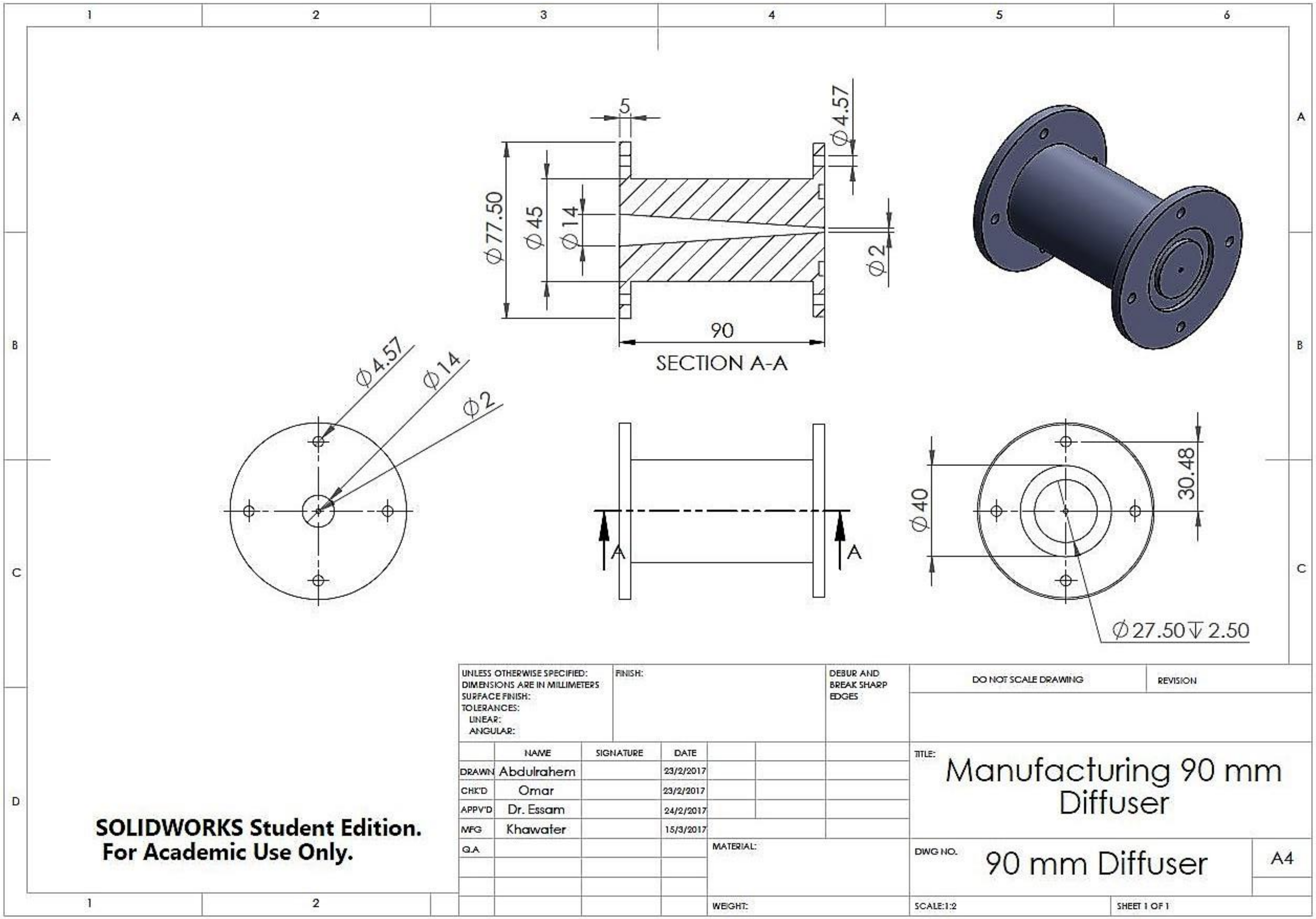

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DRAWN Abdulrahem 23/2/2017
CHK'D Omar 23/2/2017
APPV'D Dr. Essam 24/2/2017
MFG Khawater 15/3/2017
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WEIGHT:
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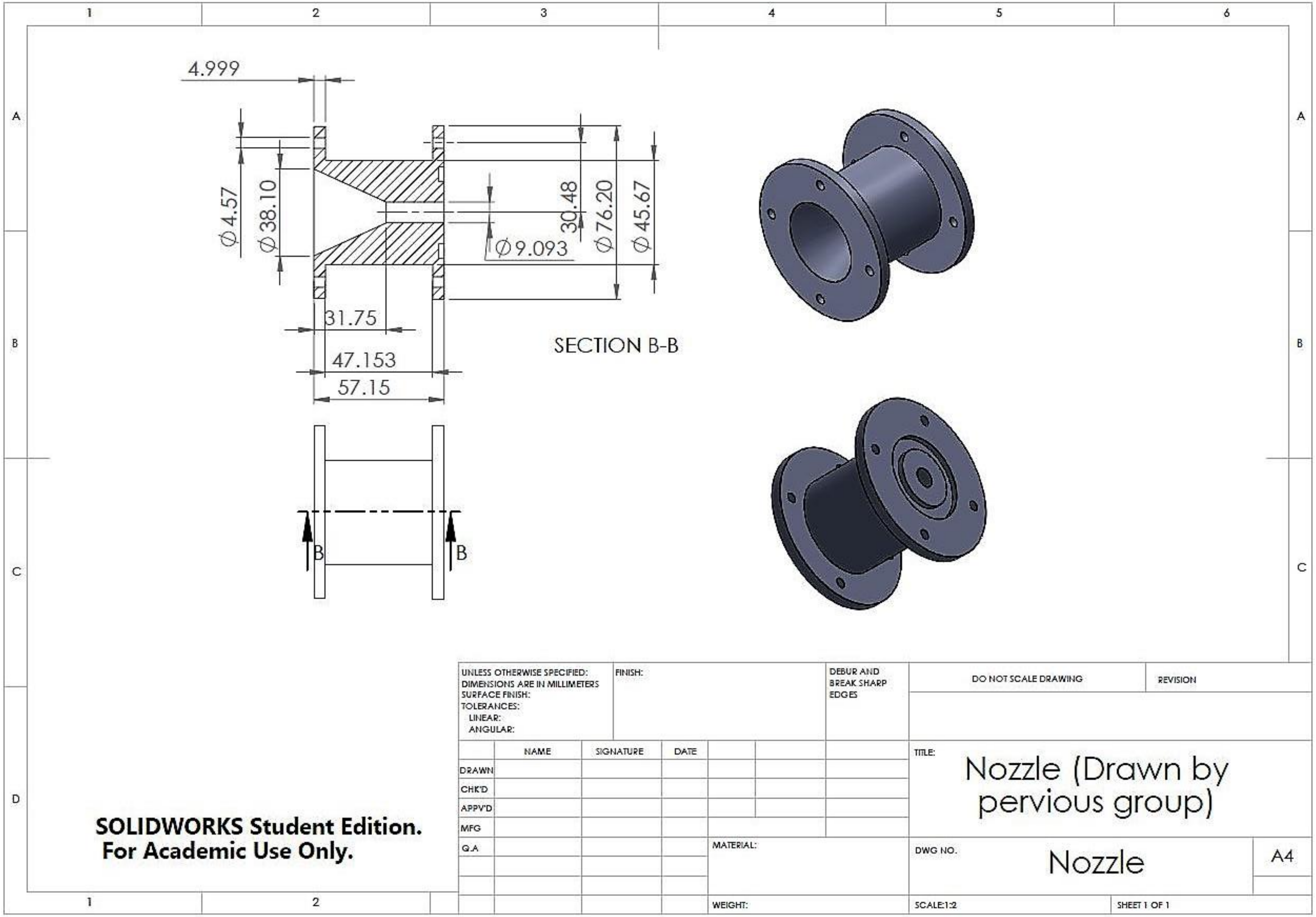
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APPV'D
MFG
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WEIGHT:
TITLE:
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Nozzle
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SHEET 1 OF 1
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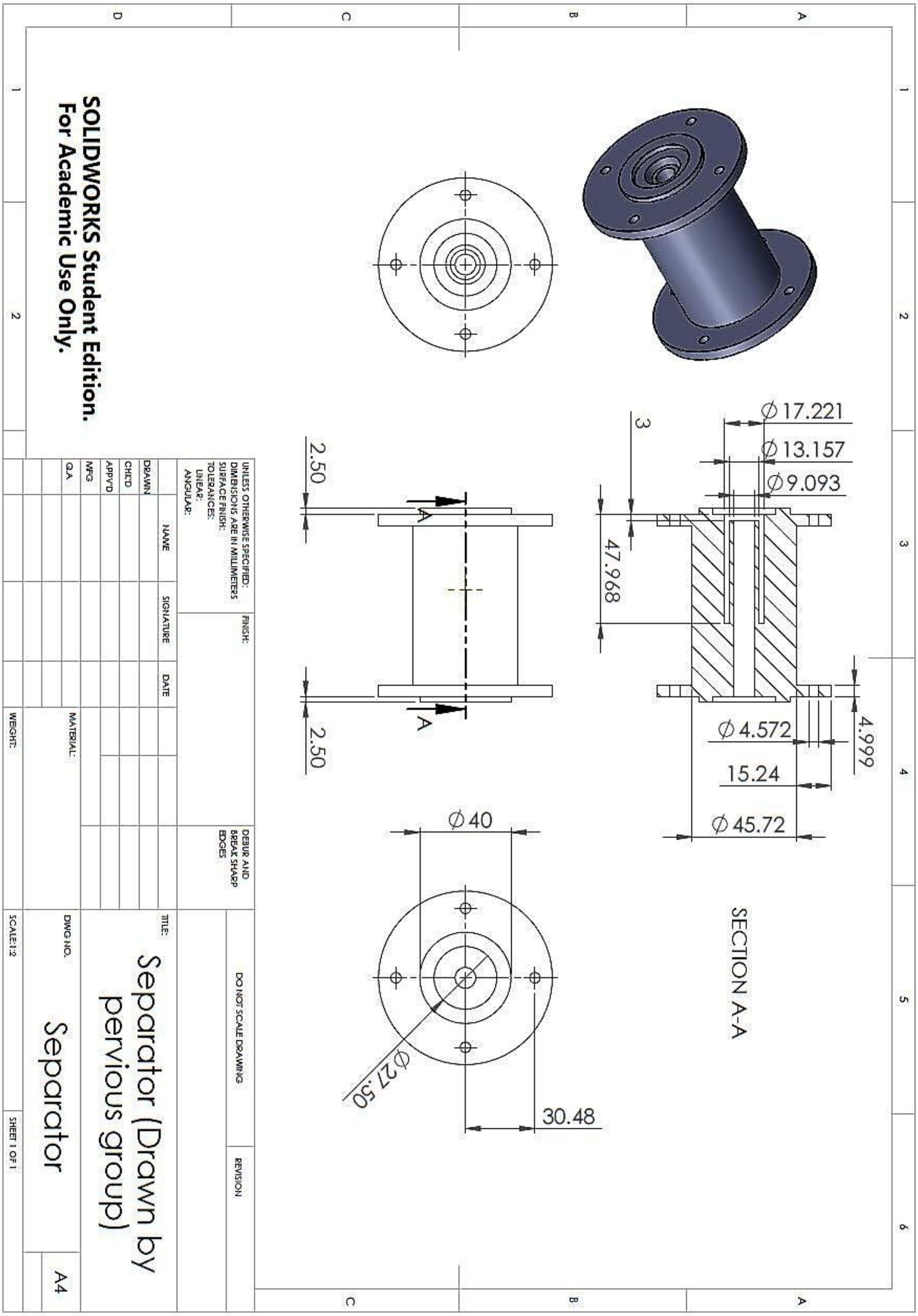
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MFG
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TITLE:
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DWG NO.
Separator
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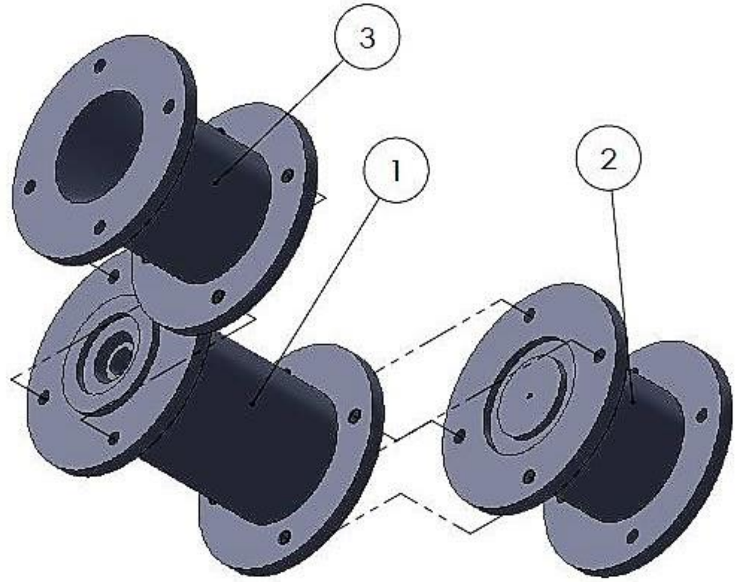
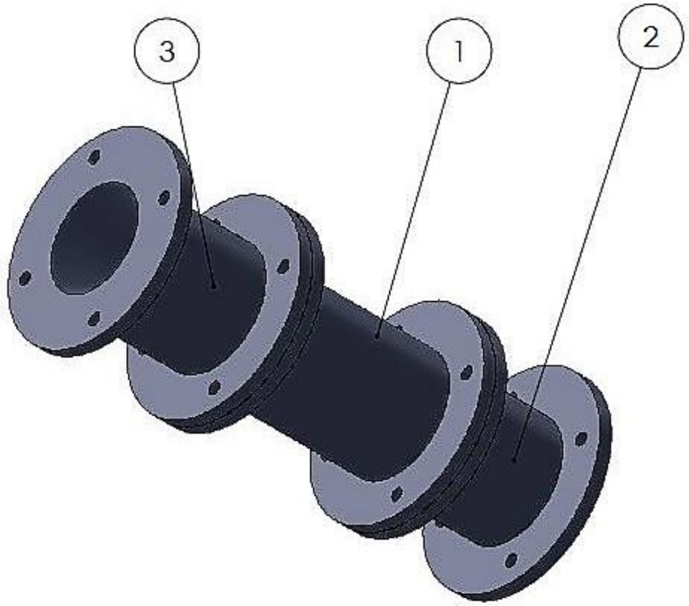
SHEET 1 OF 1





ITEM NO.	PART NAME
1	Separator
2	Diffuser
3	Nozzle

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	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Abdulrahem		23/2/2017	Supersonic Nozzle Sperator System with 50 mm Diffuser	
CHK'D	Omar		23/2/2017		
APPV'D	Dr. Essam		24/2/2017		
MFG	Khawater		15/3/2017		
Q.A			MATERIAL:	DWG NO. Assembly	A4
			WEIGHT:	SCALE:1:2	SHEET 1 OF 1