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College ofEngineering

Department of Mechanical Engineering

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Senior Project Report

Design of thermal Driven Supersonic Ejector Based on Heat Pump

In partial fulfillment of the requirements for the Degree of

Bachelor of Science in Mechanical Engineering

Team Members:

1	Nassir A Al-Baijan	201501005
2	Abdullah H Al-Hammad	201502929
3	Anas A Al-Omair	201502942
4	Saeed M Al-Zahrani	201402965

Project Advisors:

Prof. Mohammad El-Hassan

Abstract

The aim of designing thermal driven supersonic ejector-based heat pump, is to use the ejector instead of a compressor in the refrigeration cycle, where thermal energy source can be used. The main purpose of this technology is to use waste heat or free renewable energy, which can perform through a refrigeration system to achieve a desired output. This project is based on the concept and theoretical aspect of Thermodynamics, heat transfer, turbomachinery, fluid mechanics, and materials engineering that have been conducted in Mechanical engineering department at PMU. This project consists of multiple phases process using low boiling temperature fluid in addition to heat added and heat removed. The requirement for this project is to have the essential component of heat pump cycle starting from the generation power section, leading to the ejector, using water as primary and secondary fluid. In addition, using heat pump cycle which consists of a condenser where the fluid would be at superheated state which heat will be removed "Qout", also an expansion valve will operate to drop the pressure at a saturated liquid state, where the cooled fluid passes through the evaporator at saturated mixture state in that stage heat addition occur "Qin". Furthermore, the major change in this project is the ejector which will be a replace instead of a compressor in the heat pump cycle. The ejector has six main parts that form basic ejector, starting from the steam chest where the primary fluid inlet, it continues through section chamber where the secondary fluid inlet, then continuing to the steam nozzle leading to the mixing chamber throat section and outlet diffuser where the converging-diverging process happen.

Acknowledgment

We would like to express our deepest appreciation to all those who provided us the possibility to complete this project. A kind appreciation to our senior project advisor Prof. Mohammad Al - Hassan, whose contributing in stimulating suggestions and encouragement helped us to coordinate our project especially in putting the motivation in us and also in writing this report. Furthermore, we would also like to acknowledge with much appreciation to the faculty of Mechanical Engineering Department at Prince Mohammad Bin Fahd University who were interested in helping us to proceed. We have to appreciate the guidance given by other supervisor as well as the panels especially in our project presentation that has improved our presentation skills and thanks to their comments and advices.

Special thanks toward our team Anas Alomair, Saeed Alzahrani , *Abdullah Alhammad, and Nassir Albaijan, whom participating with highly effort and extreme energy to build supersonic ejector.

List of Acronyms (Symbols)

A	Area
CFD	Computational fluid dynamics
CR	Compression ratio
c	Sound speed
c_p	Specific heat capacity at constant pressure
c_v	Specific heat capacity at constant volume
D	Diameter
ER	Entrainment ratio
η_n	Primary nozzle efficiency coefficient
η_d	Diffuser efficiency coefficient
γ	Specific heat ratio
h	Enthalpy
κ	Area ratio, $\kappa = A_{m2}/A_t$
L	Length
M	Mach number
m	Mass flow rate
μ	Pressure ratio, $\mu = P_1/P_{s0}$
ω	Entrainment ratio
P	Pressure
R	Gas constant
$\overline{R}$	Universal gas constant
ρ	Density
Δs	Entropy change
T	Temperature
τ	Pressure ratio, $\tau = P_{s0}/P_{m2}$
θ	Area ratio, $\theta = A_1/P_{m2}$

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Chapter 1: Introduction

1.1 Project Definition

- A BFE (binary fluid ejector) is a thermally-driven fluidic compressor that take place of the electro-mechanical compressor in Reverse-Rankine thermal cycles (refrigeration systems).
- A BFE system will operate instantaneously as extreme functional heat pump, result of that it will lead to energy& economic savings.
- BFE system could be driven by several application of low-grade thermal energy, involving: solar energy, geothermal, stack flue gas, waste heat, engine exhaust, biogas, biomass and other kinds of fossil fuels.
- BFE is a technology that is applicable in vast universal implementation, including (cooling& heating) refrigeration cycles, industrial-scale desiccation, distillation and desalination, also recover the wasted heat and re-use the dissipated heat.

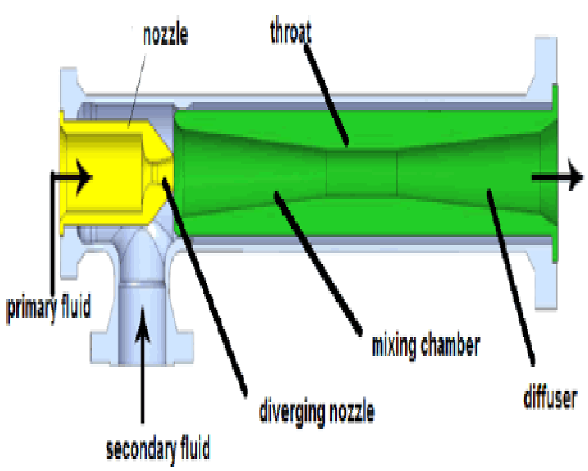


Figure 1.1: Binary fluid ejector schematic

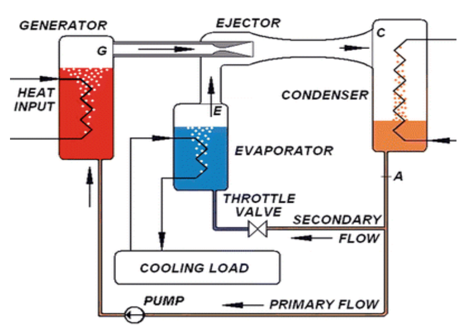


Figure 1.2: Binary fluid ejector in refrigeration system

An ejector is a device in which a fluid at high pressure at A is accelerated through a primary nozzle and after that high speed primary jet entrains and compresses a secondary fluid at low pressure at B, the 2 streams combine together before entering the diffuser at D where the kinetic energy converts to moderate pressure. The conventional jet ejector design has four major sections:

- **Nozzle** where the high-pressure fluid begins accelerated
- **Suction** chamber where entrainment happens
- **Throat** where the 2 streams combine together
- **Diffuser** where the final pressure is achieved

1.2 Project Specifications

This project will consist of one sub system which will operate the thermally driven ejector and that will consider as the main source of energy for this project. The sub system is a solar system that will collect the energy from the sun and the heat will be transferred to the storage tank where it’s connected to the generator, and the generator will provide the ejector with steam to let the operation goes as shown in figure (1.3).

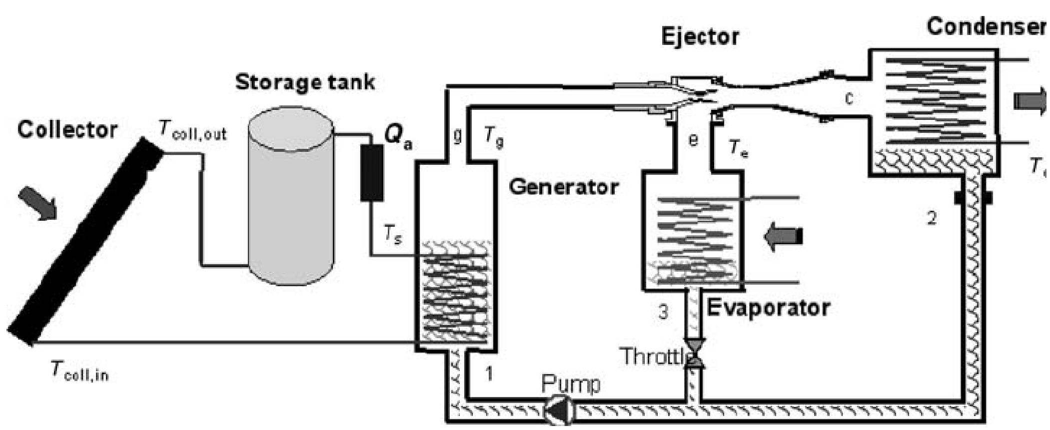


Figure 1.3: Schematic of solar driven ejector refrigeration system

From the economical view, this project is very good where it will reduce the consumption of electricity be using the ejector instead of the electro- mechanical compressor in the refrigeration system. Moreover, this project going to be an environmentally friendly where it will use the renewable energy to operate the system.

1.3 Applications

The supersonic ejector system is broadly used in various industrial utilities, and has an important role in many applications.

1. Cooling/heating is the most favorable and widely use application for ejectors, in air-conditioning or heat pump systems is basically replacing a total mechanical compressor with an ejector to perform a compressed flow, it can work without mechanical energy consumption.

2. Desalination of seawater system is an important system in any industrial shores factories, by using renewable energy and thermally driven ejector in order to achieve full sustainable and environmental desalination water plant.

3. In aerospace engineering, ejector systems are mainly used for turbojet thrust augmentor in pulsejet engines, mixing the exhausted air with fresh air to reduce the thermal or heat signature, even though to suppress exhaust noise.

4. In petroleum industry, most of oil and petroleum refineries have a multiple of applications for ejector systems, such as vacuum flasher, lube oil distillation and recovering natural gas from oil/gas mixture in oil tanks, those application is one of typical ones.

Chapter 2: Literature Review

2.1 Project background

Henry Giffard invented the condensing ejector in 1858. Also the ejector has been developed many times by a lot of innovator and researchers. The ejector is a flow device that permits a high pressure fluid, termed the primary fluid, to get on a low pressure fluid (the secondary fluid) into the flow path, and discharge the mixed flow at an intermediate pressure that is higher than the secondary flow pressure, so the ejector acts like a compressor or a pump, however with none moving parts, lubricants and maintenance.

Generally, the ejector has four parts: a nozzle which could be convergent shape or convergent-divergent shape, a suction chamber, a mixing chamber (a convergent part and a constant-area part) and a diffuser, as illustrated in Figure 4. The main geometry is characterized by the area ratio, which is defined as the area of the constant-area part in the mixing chamber divided by the nozzle throat area.

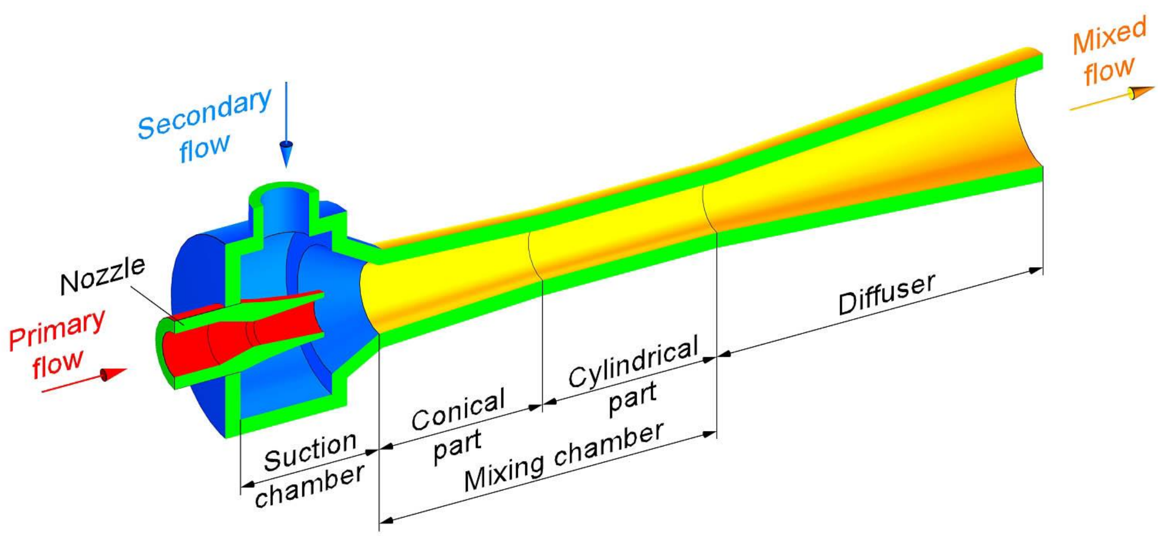


Figure 2.1: Schematic drawing of the ejector with a convergent-divergent nozzle.

The primary flow acts as the motive fluid for the ejector, while the secondary flow is the driven fluid. Both the primary and secondary flows can be in any flowing state, like liquid, vapor and two-phase. They can also be pure fluids or mixtures of non- identical fluids. The common ejector types are summarized in Table 1 (Elbel, 2011). Depending on its applications.

Table 2.1 Various ejector types (Elbel, 2011).

Types	Primary flow	Secondary flow	Outlet flow	Remarks
Vapor ejector	Vapor	Vapor	Vapor	Two-phase flow can occur, shock waves possible
Liquid ejector	Liquid	Liquid	Liquid	Single-phase flow without shock waves
Condensing ejector	Vapor	Liquid	Liquid	Two-phase flow with condensation of the primary flow, strong shock waves
Two-phase ejector	Liquid	Vapor	Two- phase	Two-phase flow, shock waves possible

In 1926, Follain introduced a multi-stage steam jet refrigeration machine. There was a lot of interest in this type of system to condition the air for large buildings within the early Nineteen Thirties. Around 1955, a Russian engineer, Badylkes, was the primary to develop the closed vapor jet refrigeration systems and used refrigerants apart from water. However, it absolutely was step by step replaced by the more efficient vapor compression refrigeration systems. The development and refinement of the ERS have been almost discontinuation since most efforts are dedicated to vapor compression refrigeration systems. As the energy and environmental problems arise throughout the last 20 years, the ejector refrigeration systems have attracted intensive and revived attention by using varied operating fluids and completely different ways, so the ejector refrigeration systems (ERS) would play a critical role in unlocking the wide spread use of renewable energy like waste heat, solar thermal, and geothermal. Even in the absence of renewable energy, such a device would enable fuel change from electricity to natural gas, which might save sixty-five to seventy five percent on energy prices, reduce GHG production, and relieve the power grid during peak times. The ejector refrigeration systems (ERS) have the potential to fill this important technology gap. Because refrigeration type thermal dynamic cycles cut across all sectors of the economy, the ERS is a platform technology with the potential for transformational impact on global energy use and the global water supply. ERS is designed to replace the mechanical compressor used in traditional refrigeration systems. These thermal cycles consume billions of kWh of electric energy and produce hundreds of millions of metric tons of atmospheric carbon each year in all over the world.

These traditional systems include space cooling (air conditioning), heat pumps (space heating), refrigerators (food storage, water chillers, etc.). In addition, vapor recompression type thermal cycles are used for such important applications as distillation, desalination, and desiccation/drying systems.

2.2 Previous Work

This previous study showed an experiential investigation of a steam ejector refrigeration system that has a moveable primary nozzle to develop the exit of the nozzle for having a high refrigeration cycle after passing through it. In addition, this study showed an experimental design for an ejector that contains two pipes that full of the different temperature of water to mean purpose. The main purpose was to decrease the temperature of the evaporator, and this process takes place when the ejector works. As, Dong, J. (2016, May 30) said that the diffusion process helps to make the molecules of water to move from high to low concentration, which helps in increasing the amount of pressure to a certain point. After increasing the pressure, there will be a chance to make the steam to move up quickly to the evaporator, and the refrigerator cycle occurs.

The idea of mixing chambers is the value here, as it helps the steam to create a layer after diffusing between the two temperature of steam so bubbles will come up, and pressure increase to the expected point to produce the maximum amount of cooling steam to the evaporator. In the current investigation, an experimental steam ejector refrigeration system was constructed. The experiments were conducted to study the influences of the primary nozzle exit position, the operating conditions, and the geometries of the ejector. (Dong, J. (2016, May 30).

Zhejiang Sci-Tech Univercity, China (Currently, School of Mechanical Engineering, Andong National University, Andong, Korea) College of Mechanical Engineering & Automation, Zhejiang Sci-Tech University, Hangzhou, China Department of Mechanical Engineering, Saga University, Japan. Supersonic ejector-diffuser procedure was extremely used in several industrial implementation. Nowadays, it is also being applied as one of the ultimate important ingredient of the solar seawater desalination facility. That is because this system has many pros compared to other fluid machinery such as no dynamics parts and no immediate mechanical energy input. The system perform of high-speed primary stream to pull the secondary stream by pure shear action for the in a target of transport or compression of fluid. Huge modification has devoted to the execution improvement of the system since it produce relatively quite low efficiency. The optimization of the ejector-diffuser system and its interpretation improvement are substantial in industrial sector. In the present study, a Chevron nozzle was used to perform the shear actions among the primary and secondary streams, by means of longitudinal vortices generated from the Chevron. A CFD method has been used to perform the ejector-system flow field. The ejector-diffuser system performance is clarified in terms of the entrainment ratio, ejector efficiency, pressure recovery as well as total pressure loss. Chevrons influences were resembled with convergent nozzle based on different principles. Beneath the Chevrons influence, more longitudinal vortices were produced and the nozzle involve more secondary stream into the ejector. The combining process was reinforced and extra energy transfer among two streams would occur. That’s why the shock wave turn into low compare to the model with convergent nozzle.

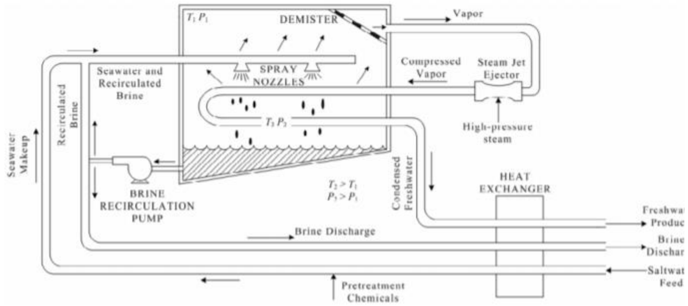


Figure 3.2: Diagram of a thermal vapor-compression plant

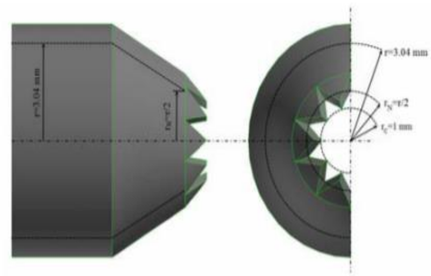


Figure 2.2 Geometrical model of the nozzle with 10 Chevrons

2.3 Comparative Study

This study was proposed in 2018 by Jingming Dong, Weining Wang, Zhitao Han, Hongbin, Yangbo Deng, Fengmin Su and Xinxiang Pan, and it was conducted on Dalian Maritime University, Dalian, China [1]. A study has been done on a steam ejector in desalination systems, in thermal vapor compression driven by low temperature heat source below 100 °C. In every desalination machinery and system uses a massive amount of fossil fuel and discharges large amounts of carbon dioxide, its been desired to outstood the disadvantages of old-style desalination technologies in order to reduce carbon dioxide discharge, by making full use of thermally driven ejector and utilizing low temperature heat sources. Figure (7) shows that the system is mainly composed of steam ejector, condenser, primary evaporator and secondary evaporator.

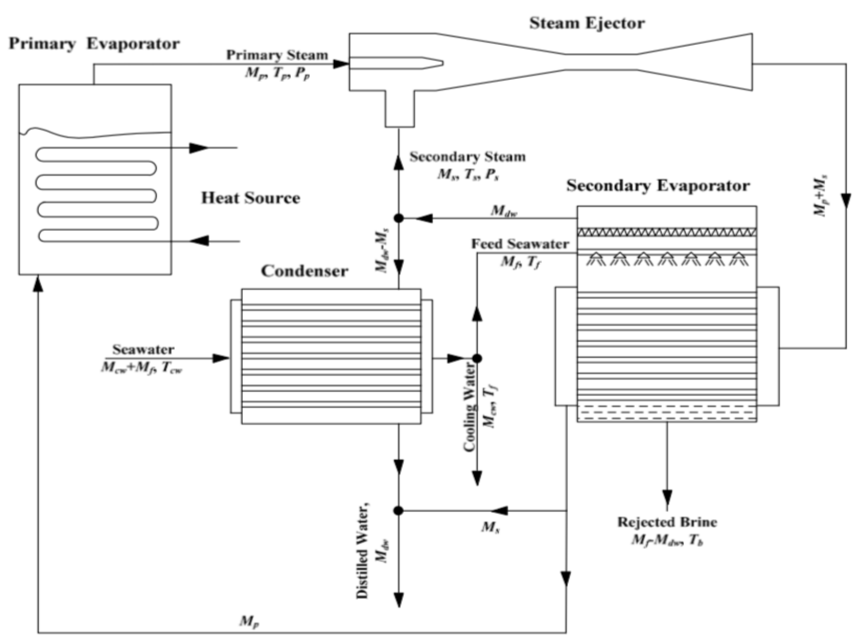


Figure 2.3: Schematic of a single effect thermal vapor compression desalination system

The experimental design of steam ejector was built and operated in order to investigate the performance and implementation of the steam ejector in a single effect thermal vapor compression (S-TVC) desalination system. The results showed that the steam ejector could work well in the single-effect thermal vapor compression desalination system, which will be driven by a heat source below 100 ◦C. The experimental results showed steam ejector could get a high coefficient of performance (COP) by increasing the secondary steam temperature inlet, and decreasing the primary steam temperature inlet.

Matthew Birnie, Morgan Galaznik, Scott Jensen, Scott Marchione, and Darren Murphy from Northeastern University College of Engineering proposed a study under the supervision of Prof. Gregory Kowalski about the Ejector in Refrigeration System [2]. This project was a complementary system works in a wasted heat that comes from 11hp air-cooled internal combustion engine exhaust. The exhaust was connected to a boiler where the water is heated to a saturated vapor and enters the converging diverging nozzle "The Ejector" to accelerate the vapor and enters the mixing champers. The ejector works as the compressor in this refrigeration cycle where the ejector doesn't need a power source to operate as shown in figure (8).

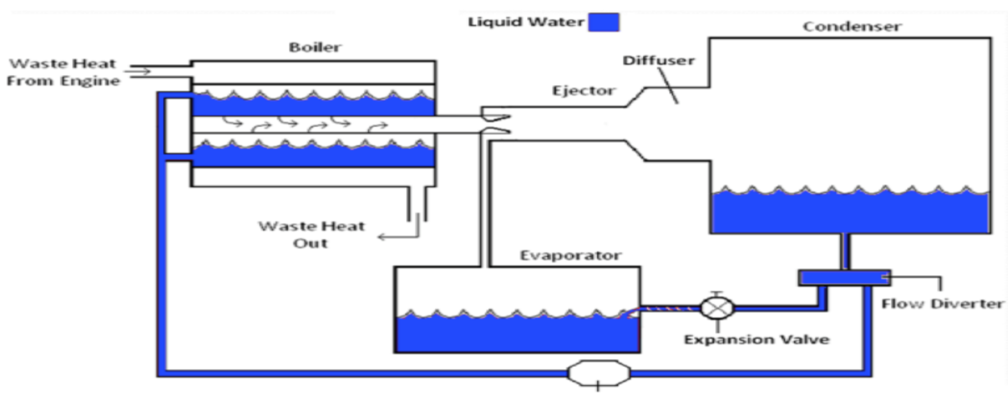


Figure 2.4: Schematic of thermally driven ejector in refrigeration cycle

The need of this project is to use the waste heat from 11hp air-cooled internal combustion engine exhaust in thermally driven ejector in refrigeration system with water as the working fluid where it operate in an ambient temperature of 39 °C while providing cooling at a temperature at 13°C.

This project can be developed and utilized to power the air conditioning system in automobile where it can work with only waste heat to minimize the usage of gas.

Another study about solar-driven ejector refrigeration system was conducted by Yosr Allouche, Chiheb Bouden, and Saffa Riffat from University of Tunis El Manar. This project consists of three sub- systems: the heating loop, the ejector cycle and the cold storage-air handling units, which will perform the air conditioning operation. This project use the solar driven ejector in refrigeration system instead of the electro-mechanical compressor to reduce the consumption of electricity. In addition, this project was designed to operate in Mediterranean countries where the climate is very hot and that cause the need of the air conditioning in these areas. This project was tested in Tunisia and Successful worked up to 3 hours. The result for the 3 hours system working dropped the water temperature form 28°C to be stable between 7°C and 13°C.

All previous studies showed the ejector in bigger scale, wither in desalination system, which is removing salt and minerals from seawater or in refrigeration system in cooling or heating. There are similarities between these studies and ours mainly in utilizing low temperature waste heat and vapor recompression in thermal cycles. What will distinguish this project than other are using renewable energy, zero energy consumption, and implementation of the most environmental friendly substances like water or air as the working fluid in the supersonic ejector based on heat pump cycle

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

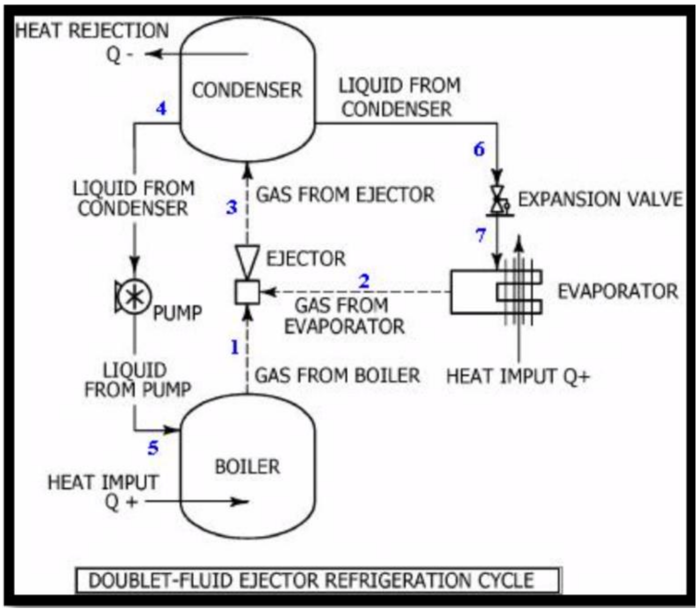


Figure3.1: Schematic View of Steam Ejector Refrigeration system.

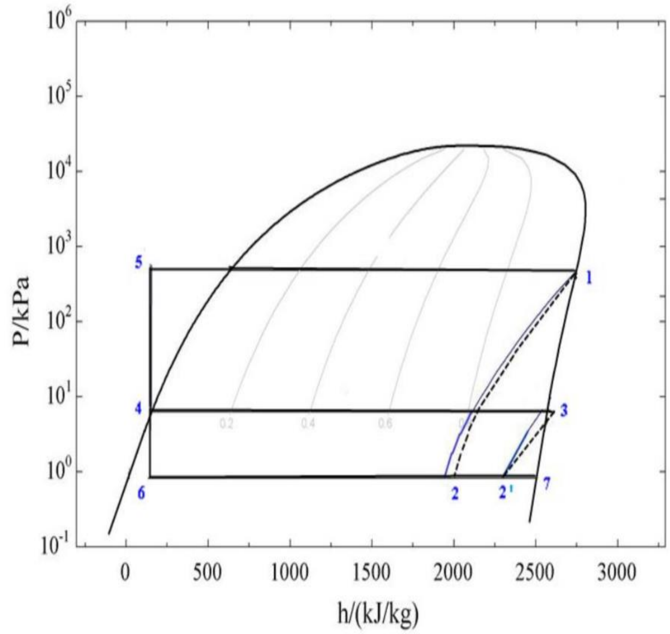


Figure 3.2: The P-H Diagram of the steam jet refrigeration system

The primary fluid at pressure at state (1) enters the primary inlet, which is the primary nozzle, accelerate and expand isentropically to the evaporation pressure at state (2). Expansion process occurs to the evaporation pressure with nozzle efficiency for the real steam, finishes at state (2). The secondary fluid from evaporator at pressure corresponding to state (7) gets sucked by the accelerated primary fluids into the suction chamber. In constant-area section at state (2') the combined fluid is supposed to be entirely mixed, in subsonic diffuser where the mixed fluid further compresses to state (3). Furthermore, the compressed mixed fluid would discharge to the condenser and cooling process occur to state (4). The leaving condensate stream from the condenser would divide into two streams; one of the two streams is pumped to state (8), and then it would enter the hot reservoir. Another stream got expanded to state (6) by the expansion valve.

- **Constraints**

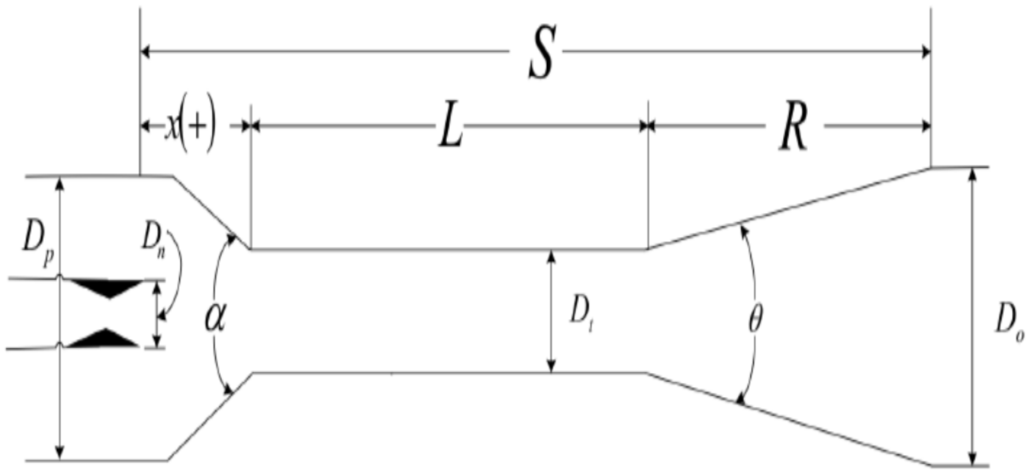


Figure 3.3: Ejector parameters

Dp: Mixing chamber diameter

Dn: Primary jet nozzle diameter

Dt: throat diameter

Do: diffuser diameter

L: throat length

R: divergent section length

X: or NXP (nozzle exit position)

α: mixing chamber angle

Θ: diffuser angle

- Choosing the proper ejector geometry is proportional to the operated system conditions and also to the fluid properties.

Ex: The performance of the ejector changes roughly due to any slight change in properties if it occurs.

- In the geometry dimensions it is preferred to use some relations.

Ex: Using the throat length equal 5Dt where Dt is the throat diameter

- **Sustainability & Environmental**

If we are investigating about sustainability, the future of supersonic ejector is represented in different viewpoint; ejector can live more than 50 years if it manufactured properly in a specific kind of stainless steel SS, no mechanical moving parts, only geometrical shape can develop a compression ratio, even though no electrical consumption, on the contrary compressor behave differently, many moving parts, frequent maintenance and require cooling.

Utilizing refrigeration cycle using compressor, huge amount of electricity consumption with fossil fuels this would result an emissions of greenhouse gases and air pollutions, which would threat and damage the environment. Therefore, improving heat pump cycle with an ejector will result less combustion of energy and that would lead to a limitation of the environmental pollution.

- **Economic**

The Entire budget should not exceed 6000 SAR

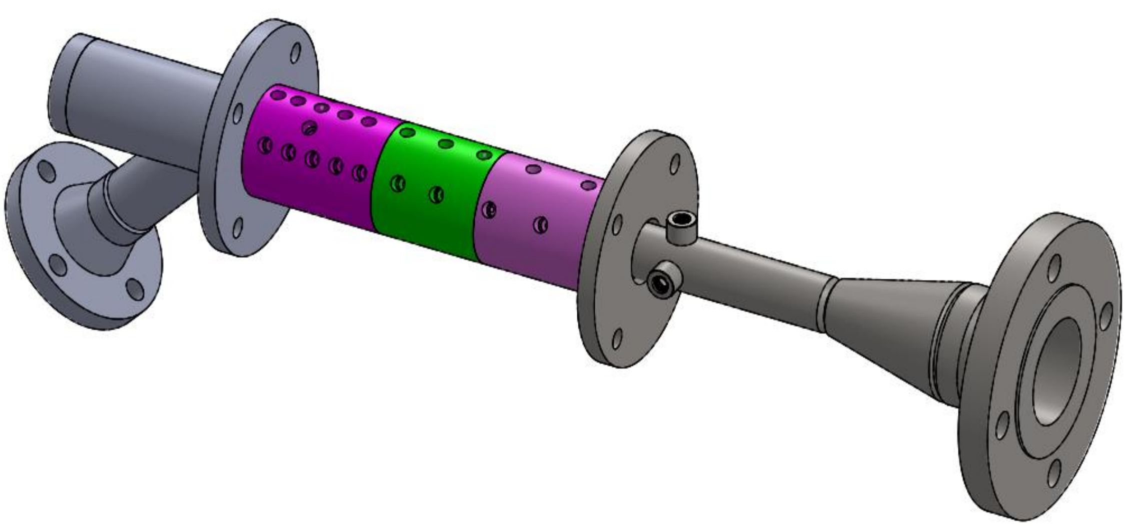


Figure3.4: Collapse View

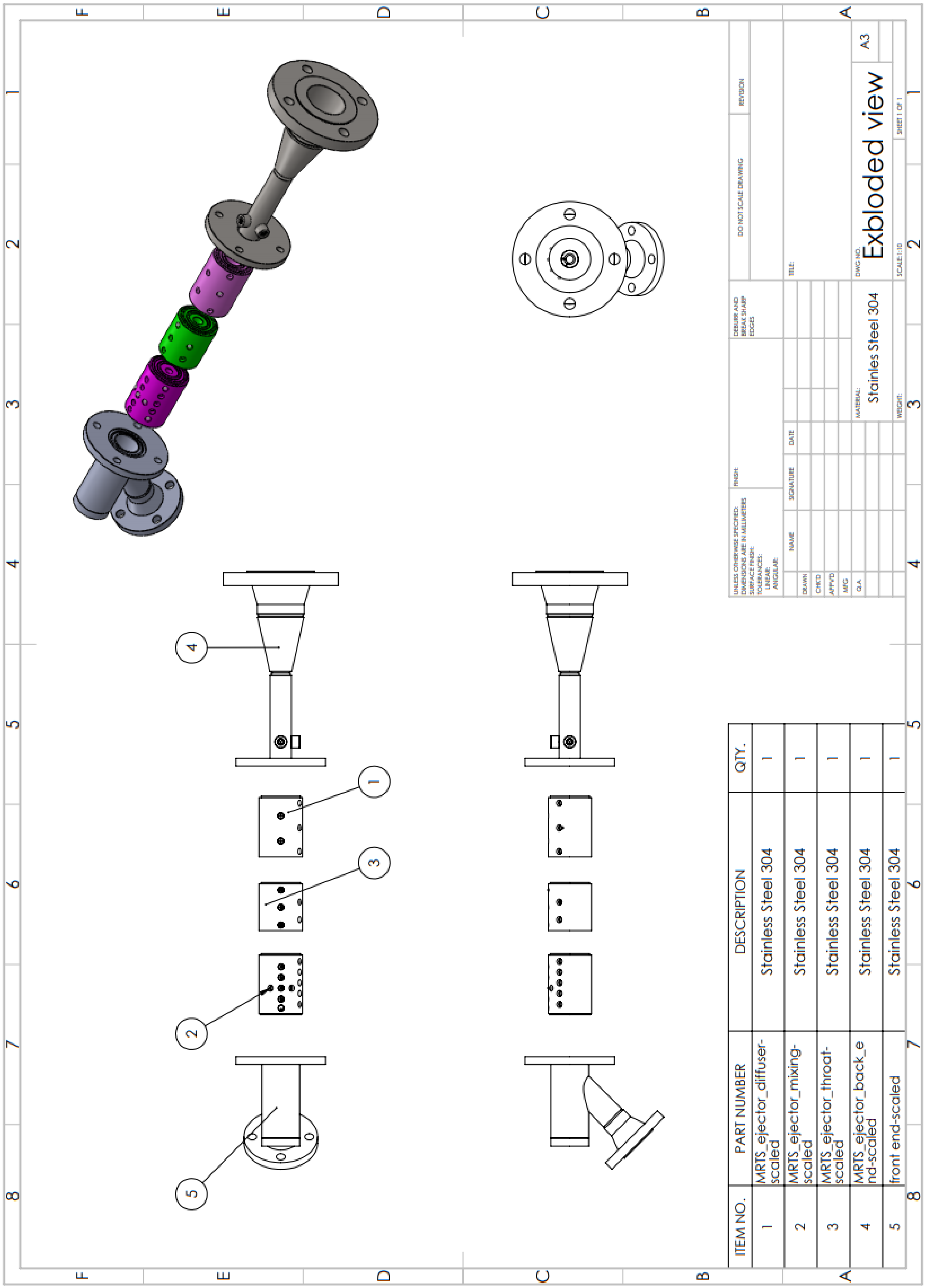


Figure 3.5: Exploded View with Bill of Materiel

3.2 Engineering Design standards:

The materiel of the ejector is Stainless Steel S30400 , ASTM 276 and the properties is shown below:

Table 3.1: Composition Specification (%)

Grade	304
Carbon (C)	0.08
Manganese (Mn)	2.00
Silicon (Si)	1.00
Phosphorus (P)	0.045
Sulphur (S)	0.030
Chrome (Cr)	18.0 20.0
Molybdenum (Mo)	--
Nickel (Ni)	8.0 11.0
Nitrogen (N)	--

Table 3.2: Mechanical Property Specification

Grade	304
Tensile Hardness Strength (MPa) min	515
Yield Strength 0.2% Proof (MPa) min	205
Elongation (% in 50mm) min	40

3.3 Theory and Theoretical Calculations

A property is any description of a substance, which may be compute and represented as quantity, e.g. temperature, pressure, mass.

Main properties that we are concerned in:

- Temperature
- Pressure
- Density
- Enthalpy
- Molecular weight

- **If two Independent properties are identified:**

Substances have several properties - but luckily it is not essential to state them all in order to describe their state.

The state of a substance might be clarified by any two independent characteristics and entirely other properties may be established if two independent properties are known.

Two characteristics are independent, of each other if one can be changing without changing the other.

- **Core guide lines for designing an EJECTOR:**

- The fluid must have a large latent heat of vaporization to allow the behavior of minimizing the circulation rate per unit of cooling capacity.

- The fluid pressure at the generator temperature need to be at intermediate level in order to eschew heavy structure of the pressure vessel and to minimize the power compulsory by pump.

3.3.1 Thermodynamics Aspect and Coefficient of performance (COP)

Generalization on ejector in refrigeration cycle model:

- The pressure losses of condenser, evaporator also the joining pipeline of system components are ignored.
- Moreover, to the condenser and evaporator, unavailability existence of heat exchange among other parts of the system and the environment.
- The throttling process operate at isenthalpic conditions.
- The sub cooling rate and evaporation and condensation temperature are identified
- The pressure of two fluids in the suction chamber are identical and the specified value, and the fluid in the ejector is one-dimensional homogeneous flow.

According on that process the next coming cycles can be illustrated as both Forward Rankine cycle and refrigeration cycle.

3.3.1.1 FORWARD RANKINE CYCLE (PRIMARY FLUID):

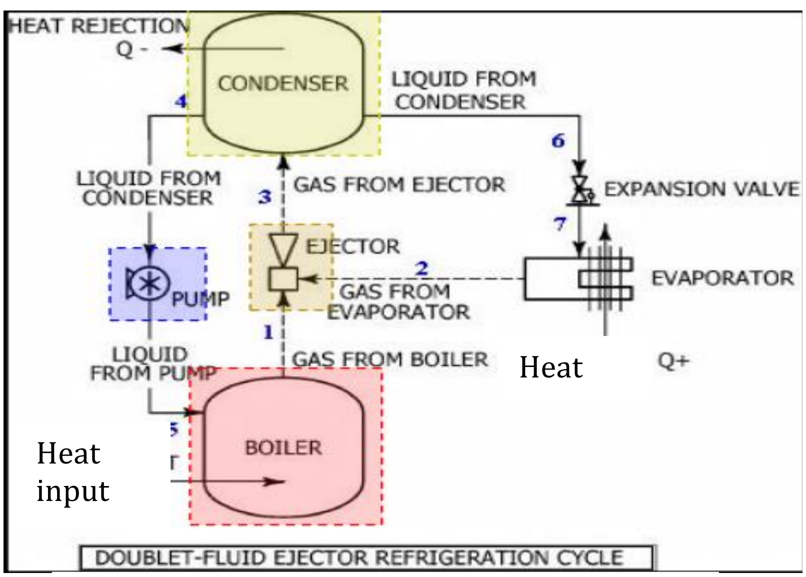


Figure 3.6: Forward Rankine cycle (Primary Fluid)

$$Q_{P,Boil} = \dot{m}_P(h_{P1} - h_{P5}) \qquad Q_{P,Cond} = \dot{m}_P(h_{P4} - h_{P3}) \quad (1)$$

$$W_{P,Ejec} = \dot{m}_P(h_{P3} - h_{P1}) \quad (2)$$

$$W_{P,Pump} = \dot{m}_P w_{P,Pump} = \dot{m}_P \frac{(P_{P5} - P_{P4})}{\rho_{P45}} \quad (3)$$

3.3.1.2 REFRIGERATION CYCLE (SECONDARY FLUID)

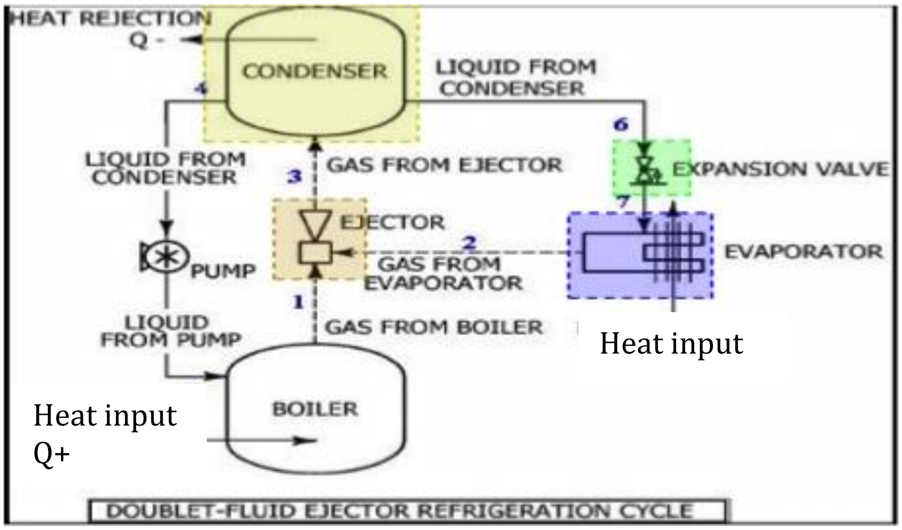


Figure 3.7: Refrigeration cycle (secondary fluid)

1

$Q_{S,Evap} = \dot{m}_S(h_{S2} - h_{S7})$

$Q_{S,Cond} = \dot{m}_S(h_{S6} - h_{S3})$

2

$W_{S,Ejec} = \dot{m}_S(h_{S3} - h_{S2})$

$W_{S,ExpVal} = Q_{S,ExpVal} = 0 \Rightarrow h_{S7} = h_{S6}$

3

3.3.1.3 COP CALCULATION

EQ.1

$$COP = \omega \frac{Hv_{Evap} + \overline{Cp_1}(T_{Cond} - T_{Evap})}{Hv_{Boil} + \overline{Cp_2}(T_{Boil} - T_{Cond})} = \omega\, f_h$$

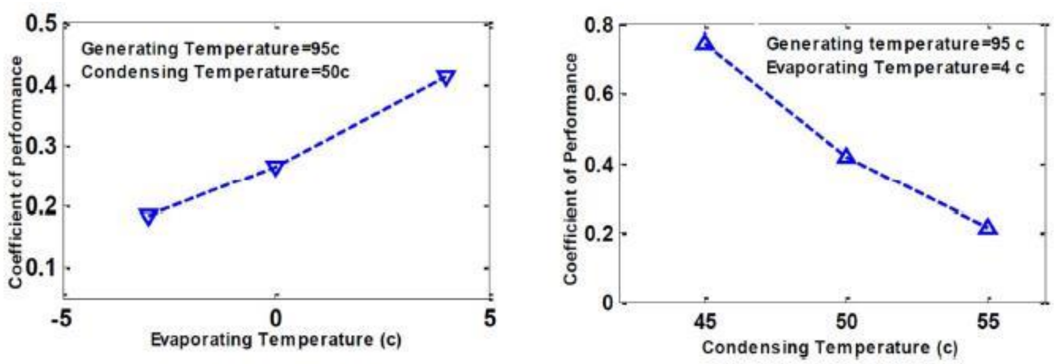
Where Hv $H_v = (h_{vap} - h_{liq})$

$$COP = \frac{\dot{m}_{sf} \cdot h_{lv,sf}}{\dot{m}_{pf} \cdot h_{lv,pf}}$$ **EQ.2**

Where COP actually is = $\frac{useful\ refrigiration}{heat\ input\ to\ boiler + power\ consumed\ by\ pump}$

We investigate the relation of coefficient of performance (COP) and we are representing the relation in different from where it is indeed existing in different academic literature reviews. Where in **eq.1** we take in consideration the temperature difference, on contract in eq.2 the temperature difference were neglect it**.**

3.3.1.4 The Effect That Temperature Has on The Ejector's Performance:



Variation of coefficient of performance versus evaporating temperature

Variation of coefficient of performance versus condensing temperature

Figure 3.8: Effect of evaporating and condensing temp on COP

If temperature of the evaporation raised up, would result a reduction in the numerator of the COP equation, it has a major impact of raising the entrainment ratio, this result an increase of the ejector's COP.

The condensation temperature would behave the same too, while increasing the temperature it would affects both denominator and numerator in the COP equation, effecting the entrainment ratio is what matters the most. The entrainment ratio would decrease due to Increasing T_{cond}, causing the ejector's COP to decrease.

3.3.2 Entrainment Ratio and Flow Constraint

What is Entrainment ratio in an ejector?

$$\omega = \frac{\dot{m}_s}{\dot{m}_p}$$

Where $\dot{m}_s$ is the mass flow rate of the secondary fluid and $\dot{m}_p$ is the mass flow rate of the primary fluid, entrainment in the ejector is about mixing two fluids with different type (two-component ejector or the binary) or the same type (the self-component ejector) having different properties (temperature, pressure,), this process occurs when the energy and the momentum is compulsively supplied by a primary fluid at high speed (the motive fluid) is transferred and accelerated to a secondary fluid.

EFFECT THAT THE ENTRAINMENT RATIO HAS ON THE EJECTOR'S PERFORMANCE:

As it's shown before in the COP equation, where the entrainment ratio is proportional to the COP, hence an increase in ω will result in an increase in the ejector's final COP as seen in the bellow graph:

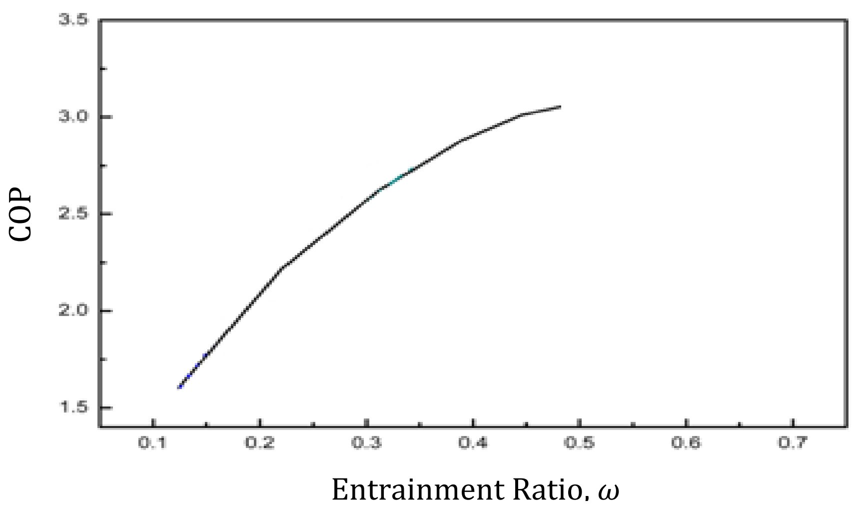


Figure3.9: COP change in function of entrainment ratio

3.3.2.1 Mach Number

Mach number "M" is one of the most important dimensionless parameter for compressible flow where density changes, specially, for supersonic flow. Mach number is defined as the ratio of the fluid velocity to the local sonic speed which is the local speed of sound.

$$M = \frac{\text{local fluid velocity}}{\text{local sonic speed}} = \frac{V}{c}$$

Classification of Mach number:

If M < 0.3 → incomprissiple flow

If M > 0.3 → comprissiple

0.8 > M > 0.3 → sonic (1^{st}shock)

1.2 > M > 0.8 → supersonic (more shocks)

3 > M > 1.2 → hypersonic

Stagnation properties in the function of Mach number are contestant all through and steady, in isentropic flow field:

Pressure: $$\frac{P_0}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

Temperature: $$\frac{T_0}{T} = 1 + \frac{\gamma - 1}{2} M^2$$

Density: $$\frac{\rho_0}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{\gamma - 1}}$$

P_o : Stagnation pressure

T_o : Stagnation temperature

ρ_o : Stagnation density

γ : Specific heat ratio $= \frac{C_p}{C_v}$

Finally, by improving the compression ratio which is pressure ratio of the discharged pressure at the diffuser to the secondary inlet pressure ($\frac{P_{out,diffuser}}{P_{sec,in}}$) the ejector could be used in wider and bigger application like desalination and distillation, etc...).

3.4 Product Subsystems and selection of Components:

In this part we used SOLIDWORK (CAD) in order to design the throat of ejector, diffuser of ejector, mixing chamber of ejector, and Back End of ejector, also select the material. All of drawing details below:

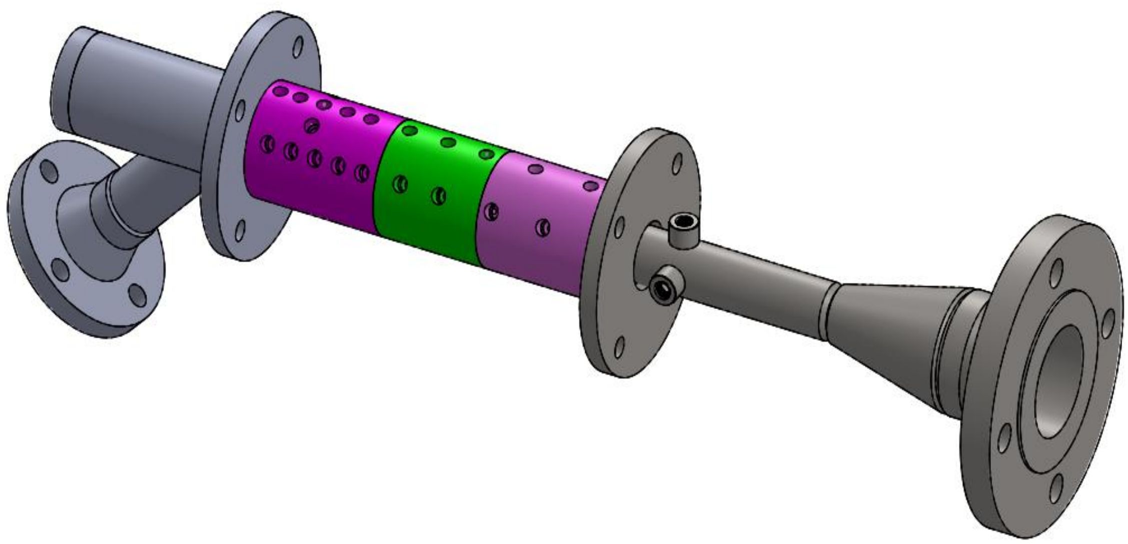


Figure 3.10: ejector assembly

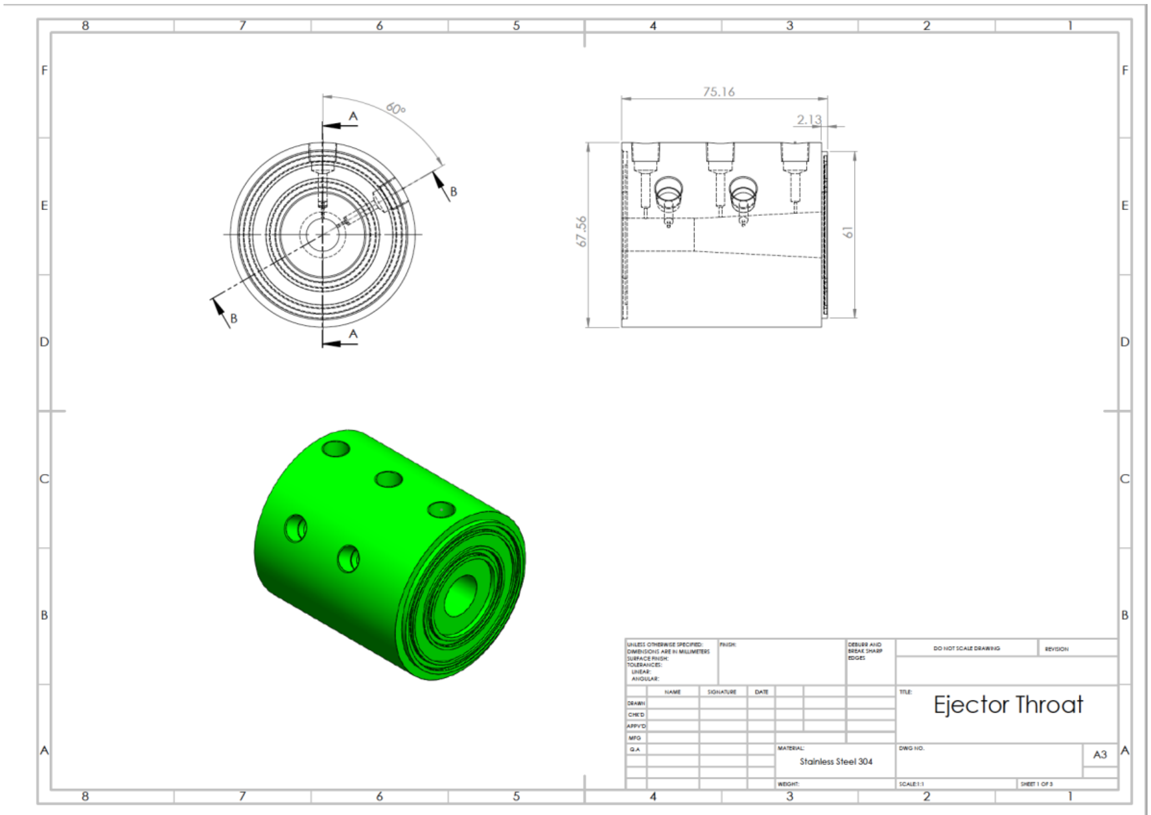


Figure 3.11: Ejector throat (SOLIDWORK)

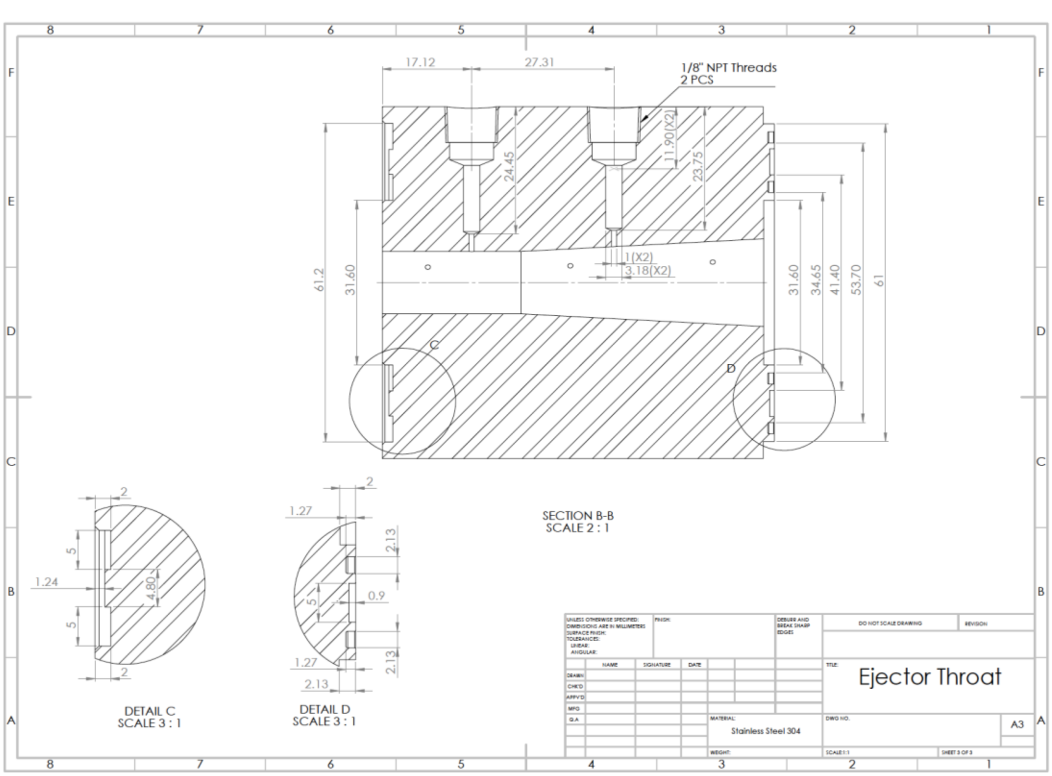


Figure3.12: Ejector throat front side (SOLIDWORK)

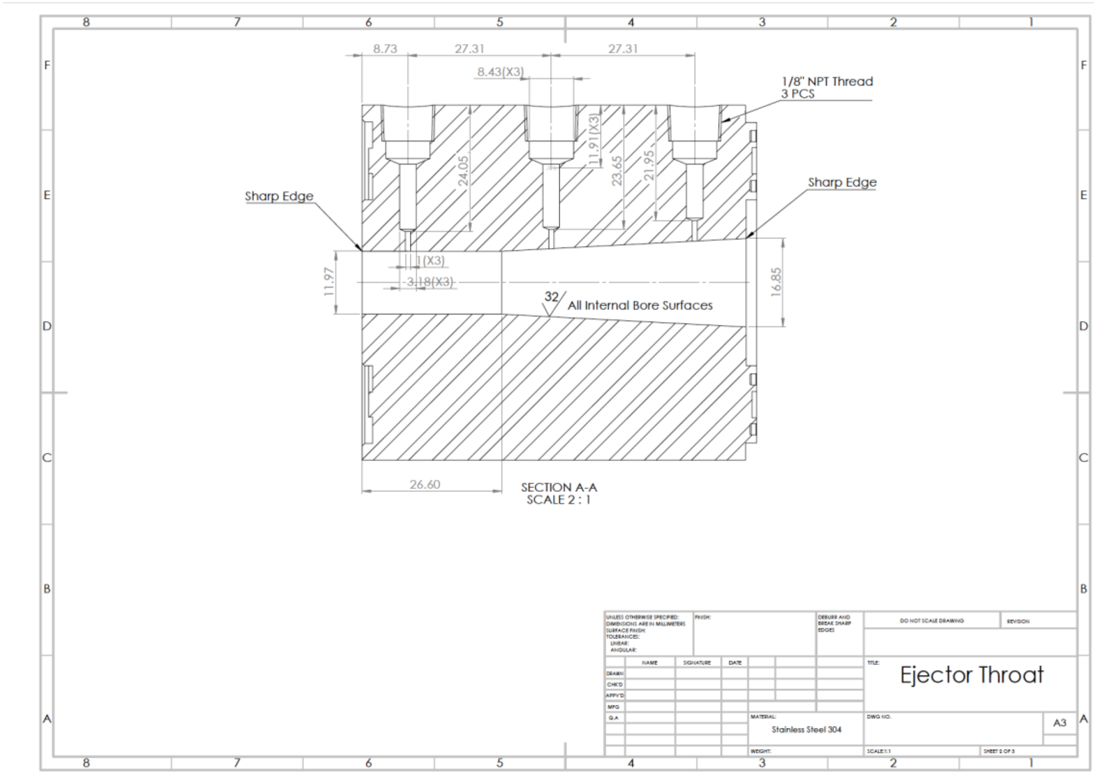


Figure 3.13: Ejector throat back side (SOLIDWORK)

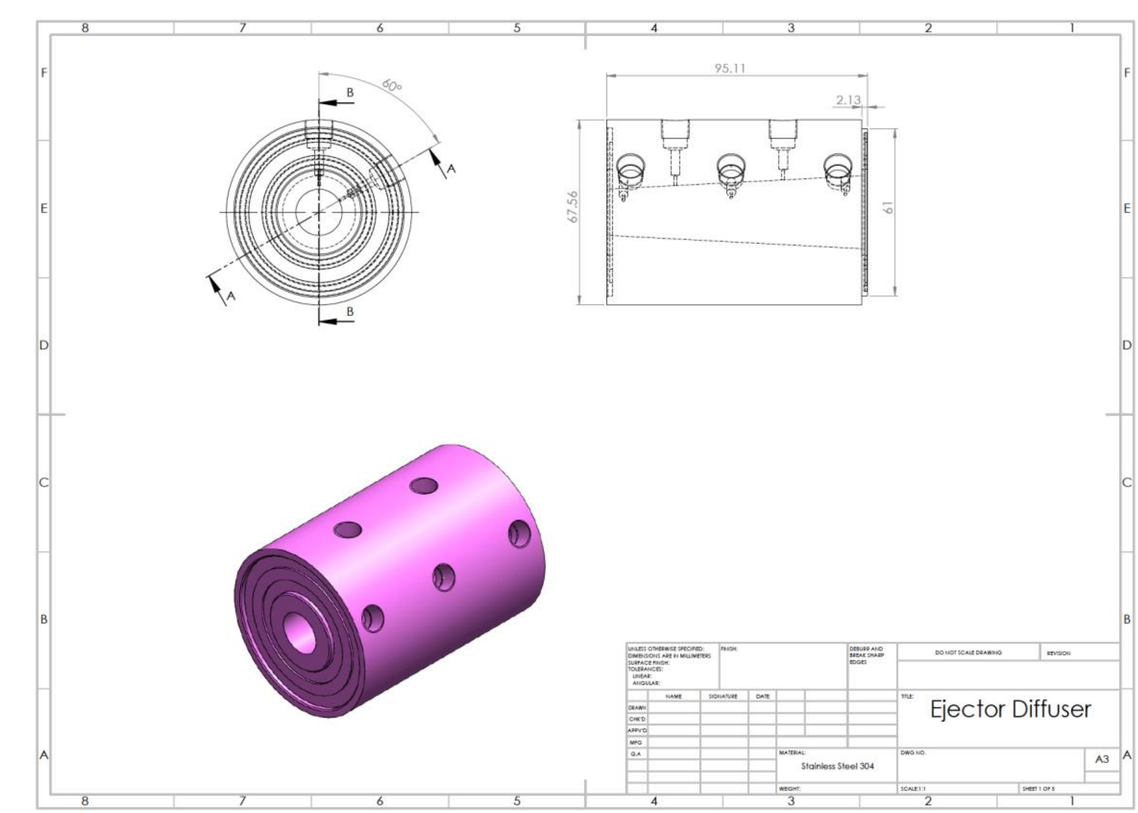


Figure 3.14: Ejector diffuser (SOLIDWORK)

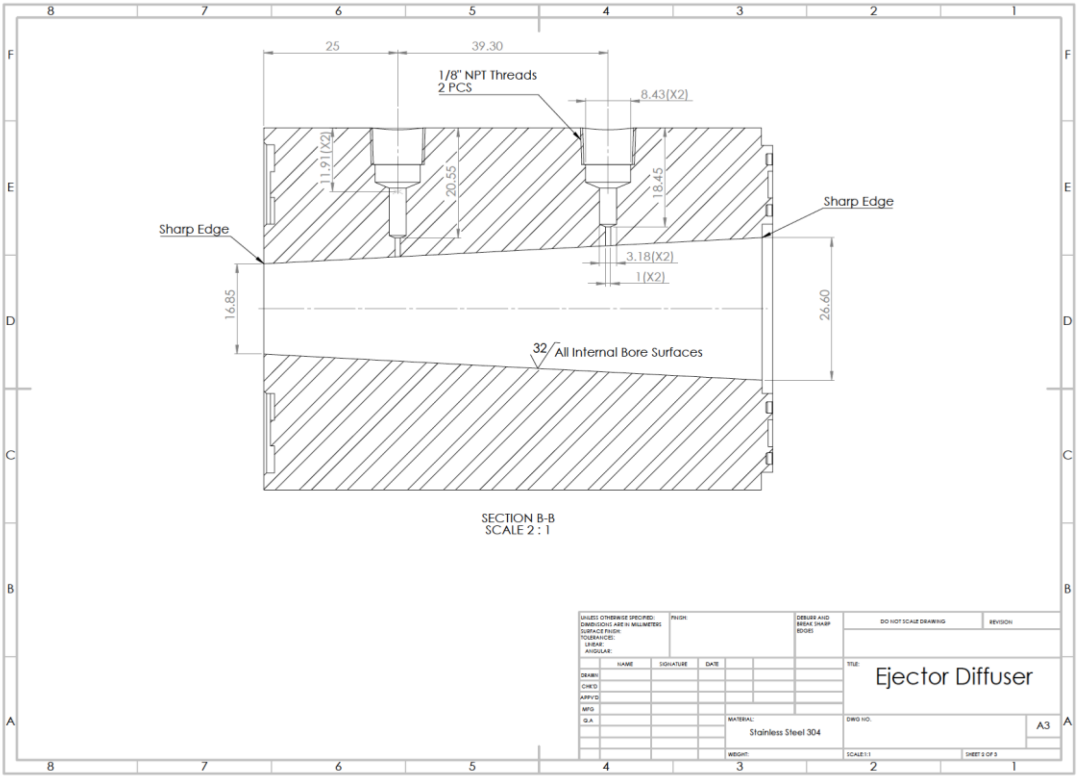


Figure3.15: Ejector diffuser front side (SOLIDWORK)

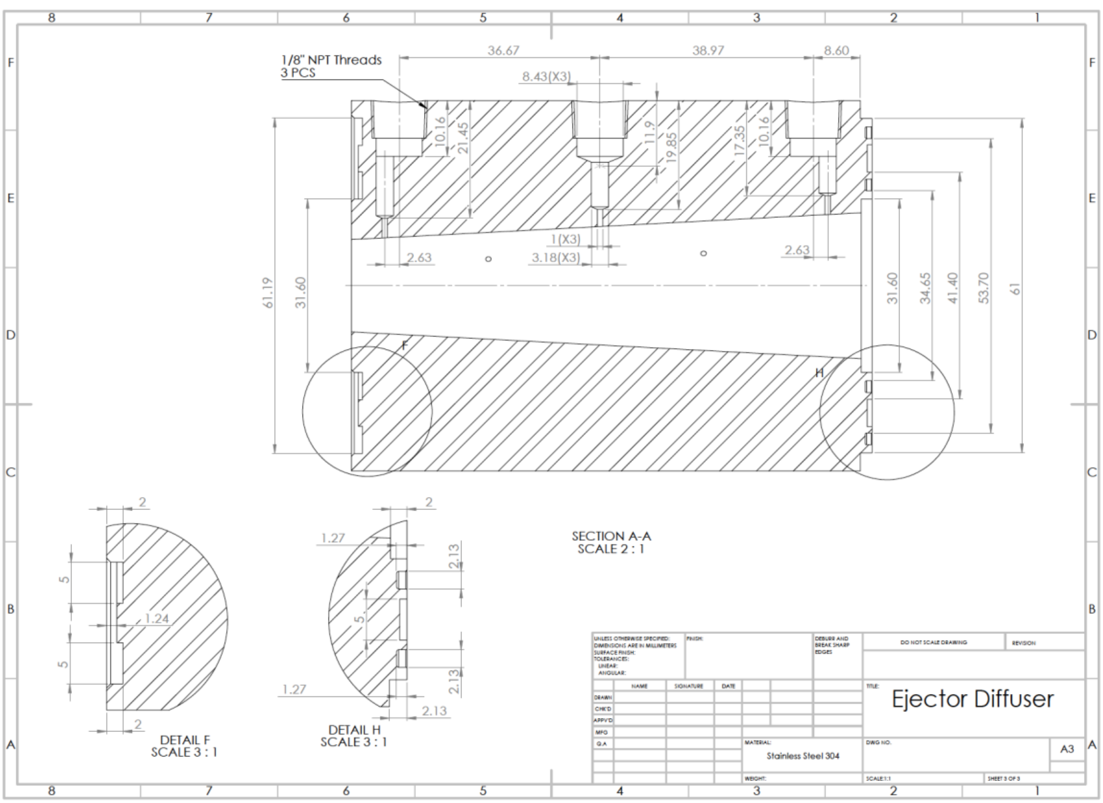


Figure 3.16: Ejector diffuser back side (SOLIDWORK)

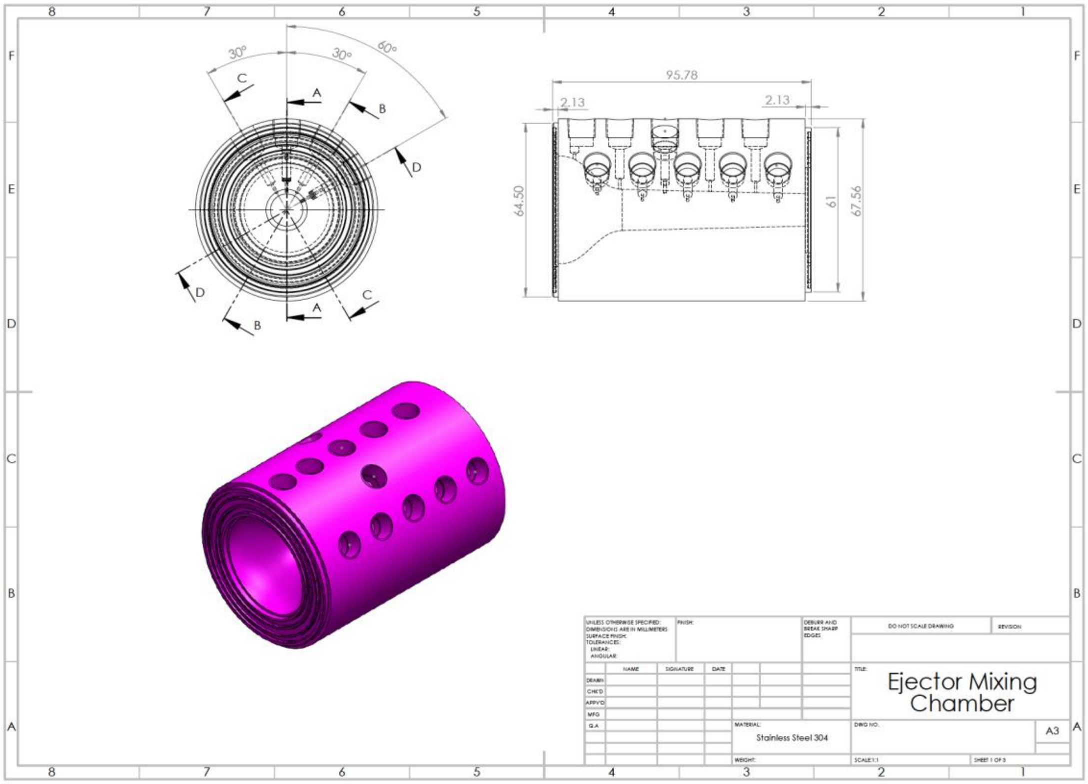


Figure 3.17: Ejector mixing chamber (SOLIDWORK)

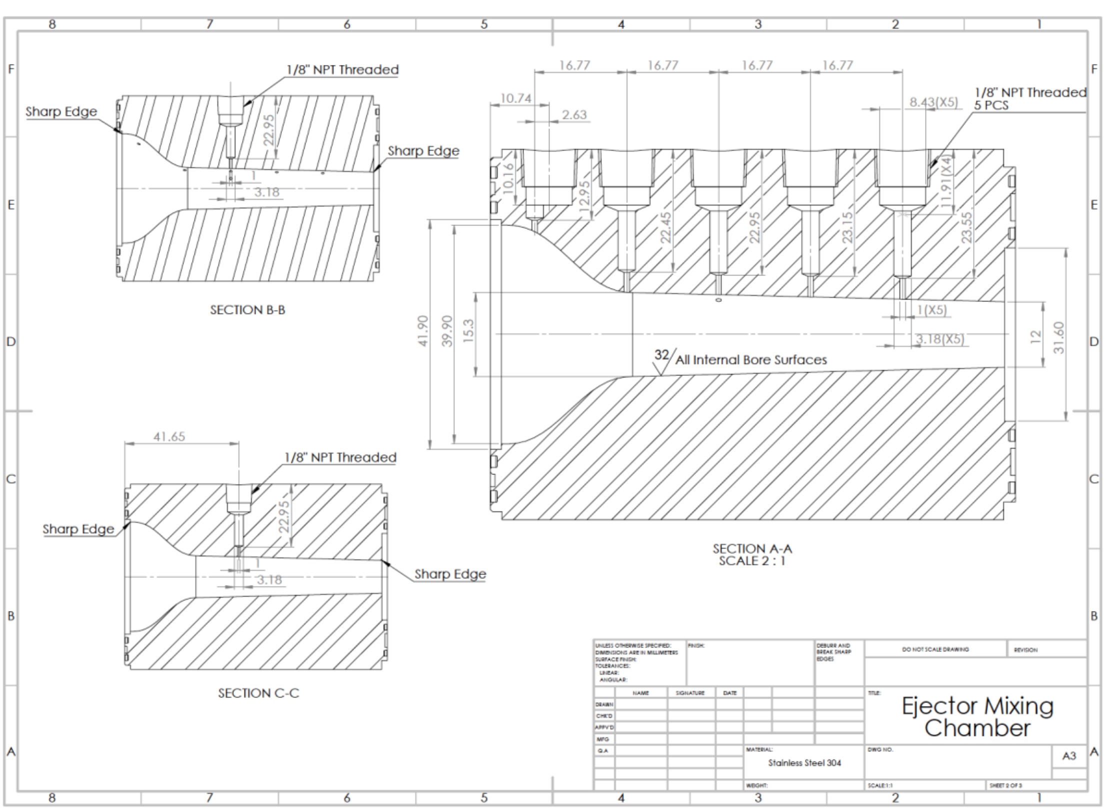


Figure 3.18 Ejector mixing chamber front side (SOLIDWORK)

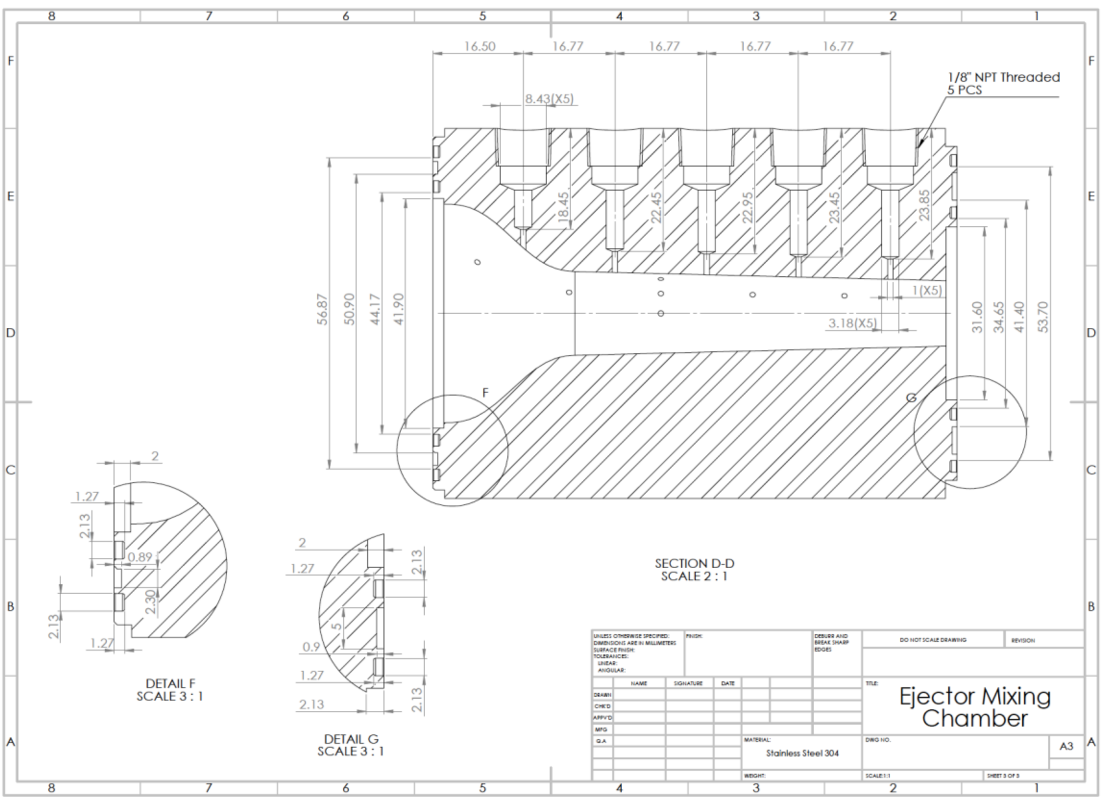


Figure 3.19: Ejector mixing chamber back side (SOLIDWORK)

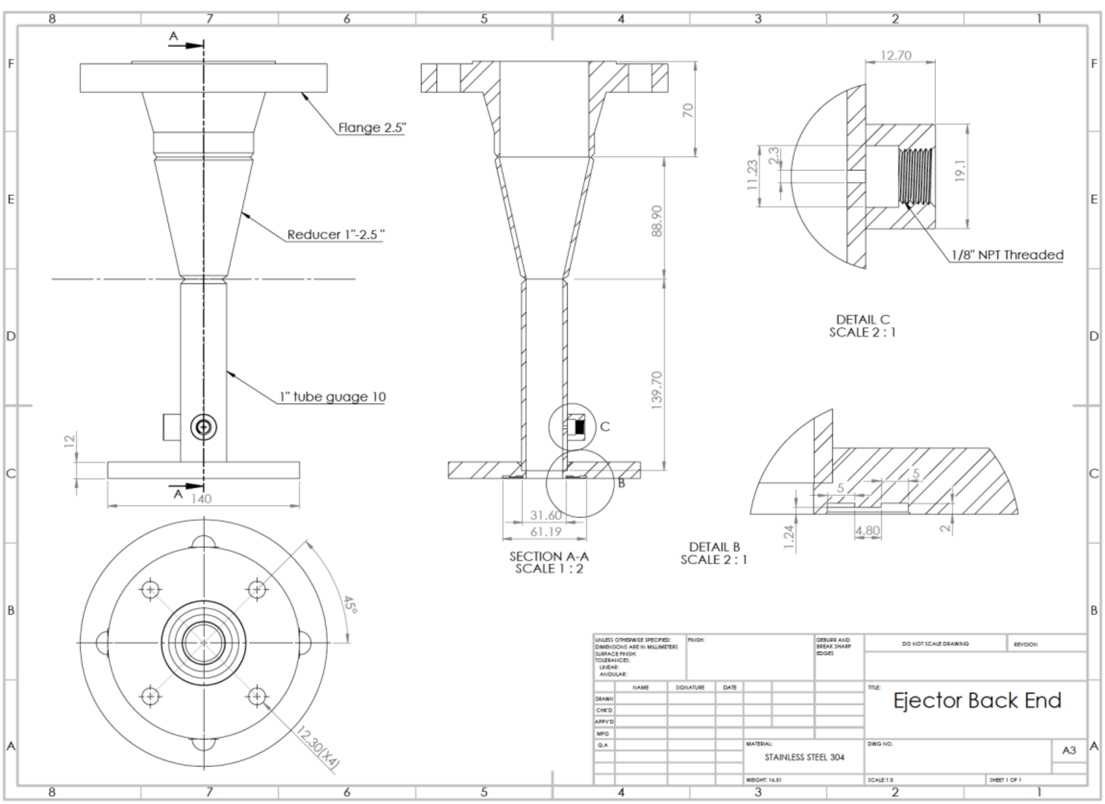


Figure 3.20: Ejector Back End (SOLIDWORK)

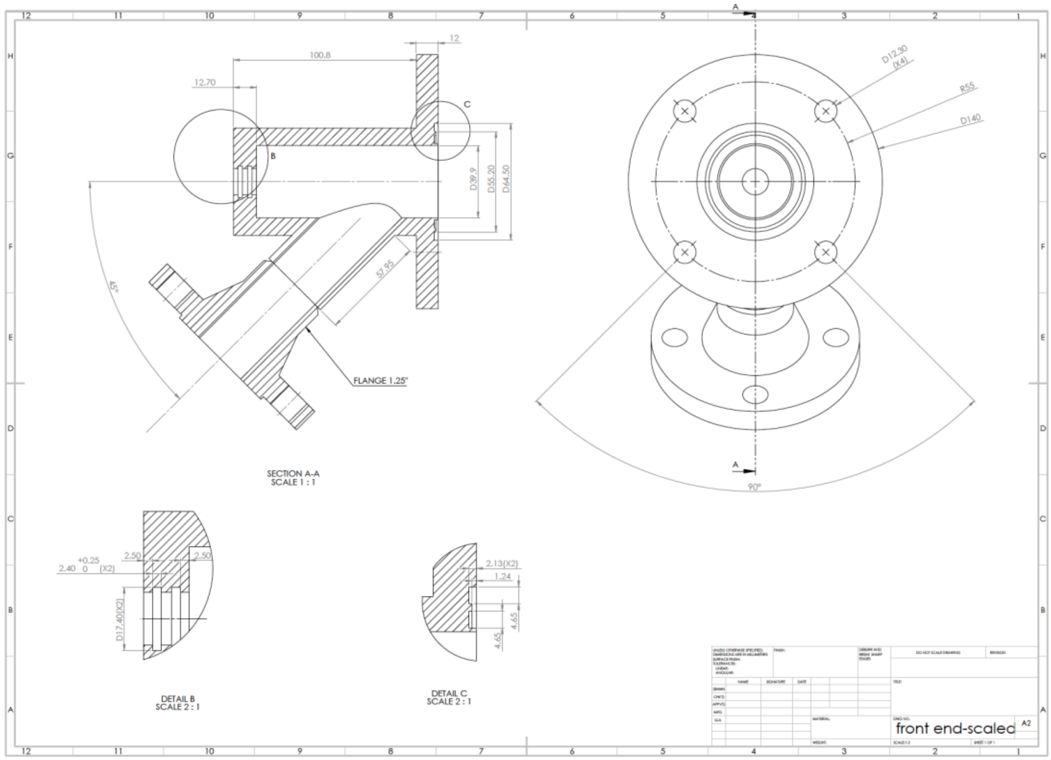


Figure3.21: Front end

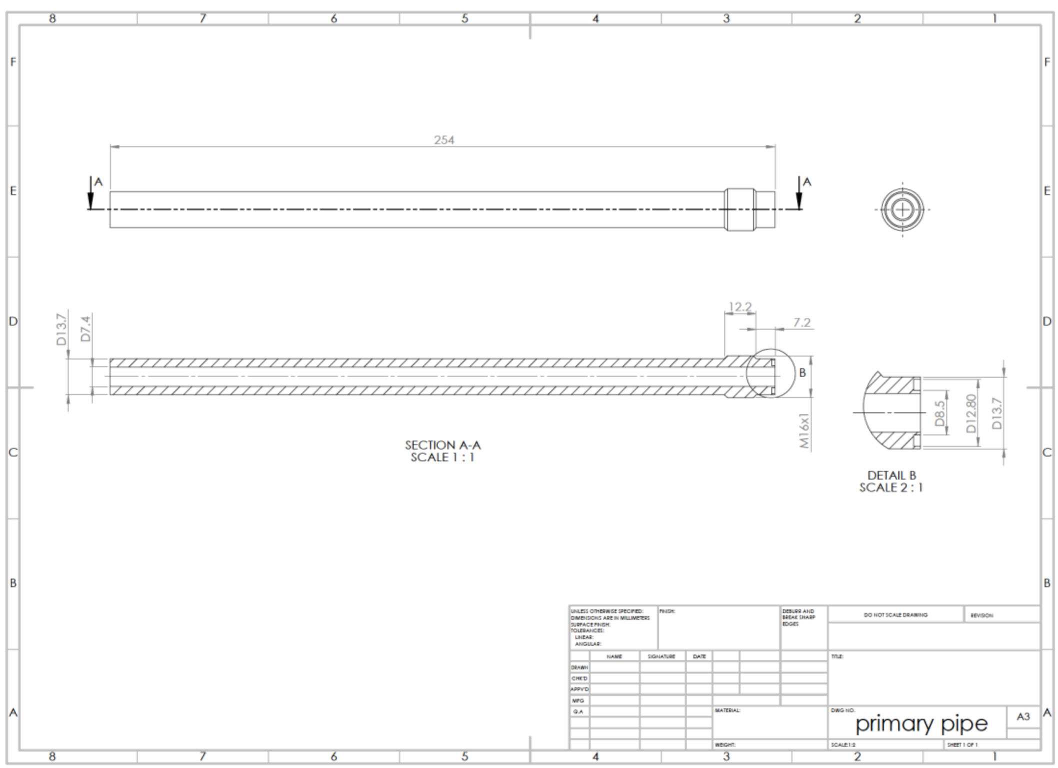


Figure3.22: Primary pipe

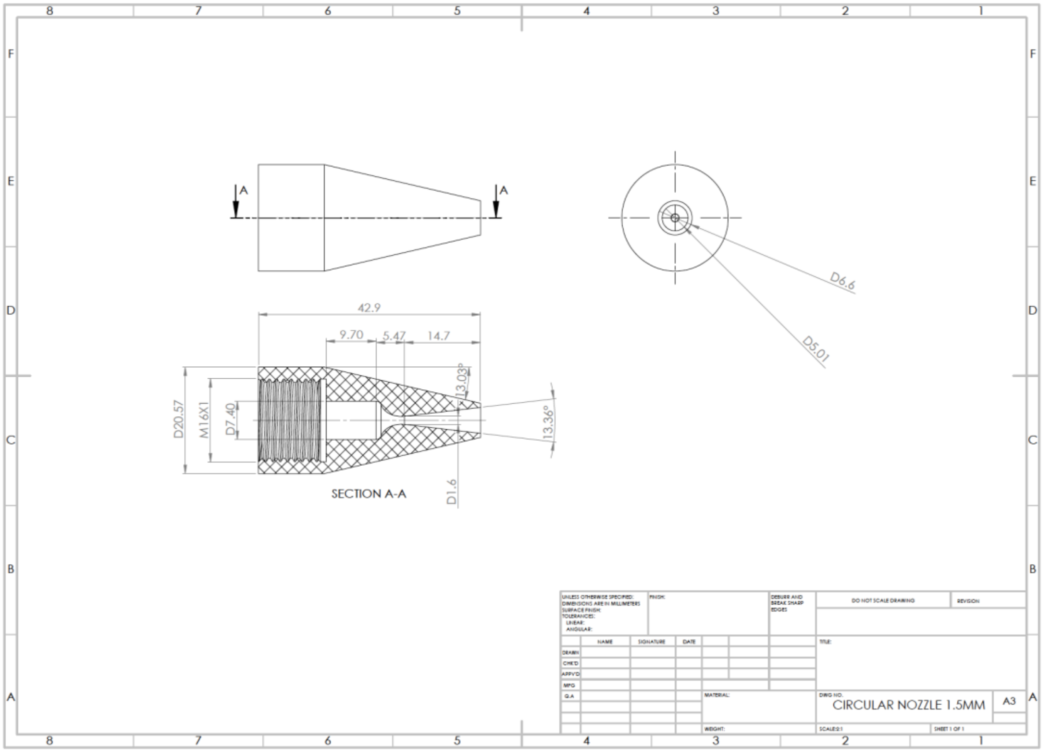


Figure 4.23: Circular nozzle

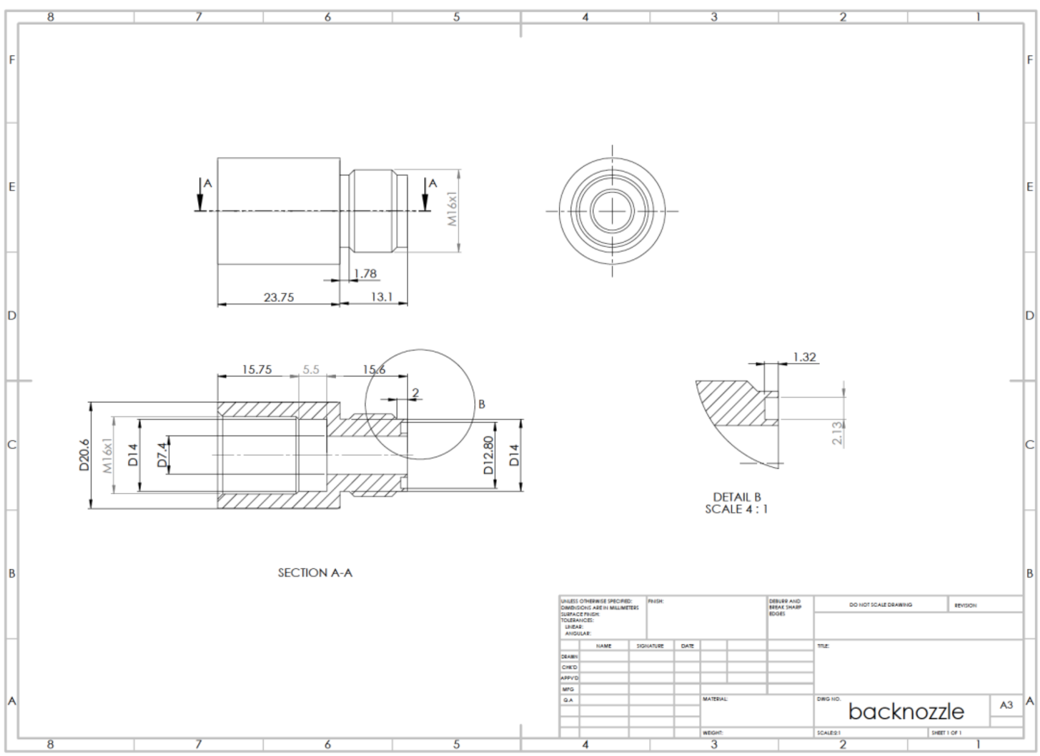


Figure3.24: Backnozzle

All the materials and sizes explained in the table below:

Table 3.3: Type of Material and Size of each Component

ITEM NO	PARTS	MATERIAL	SIZE (MM)
1	Ejector: Mixing chamber	Stainless steel 304	95.78" length 33.78"diameter
2	Ejector: Throat	Stainless steel 304	75.16" length 33.78"diameter
3	Ejector: Diffuser	Stainless steel 304	95.11" length 33.78"diameter
4	Back end	Stainless steel 304	298.6" length 91.5"diameter
5	Front end	Stainless steel 304	112.8" length 64.50"diameter
6	Primary pipe	Stainless steel 304	254" length 13.7"diameter
7	Circular nozzle	Stainless steel 304	42.9" length 20.57"diameter

3.5 Manufacturing and assembly:

In this trial selecting the right material to confirm that the system will operate correctly is a crucial process. Therefore, for the mixing chamber (Stainless steel) Clarified in (figure 29). In addition, for the part connecting nozzle & diffuser (Throat) (Stainless steel) was used (figure 30). Moreover, the diffuser & nozzle parts made of (stainless steel) (figure 31) in order to maintain the variation of the pressure and the chock behavior also to allow smooth surface and provide flow with minimum friction rate. All of these parts machined by (EDM) machine zinc electrodes.

Figure 3.25: mixing chamber

Figure 3.26: Throat

Figure 3.27: Nozzle diffuser

Front end, where Primary and secondary fluid inlet (stainless steel) illustrated (Figure 32), furthermore... Back end which connect the ejector to the vacuum pump (Stainless steel). Vacuum pump which will perform at 15 kpa and volume flow rate about 40 m^3/h. Additional accessories, Static pressure sensors which will measure the pressure under static conditions (Figure 33). Finally, Gas bottles which will contain compressed air (Figure 34)

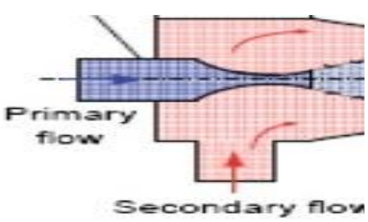


Figure 3.28: Front end

Figure 3.29: Static pressure sensors

Figure 3.30: Gas *bottle*

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

The objective of the testing is to make sure that our supersonic ejector system work in a sufficient way.

In order that our system complete the test before doing experimenting stage we did the following:

- First, we did an analytical modeling (method):

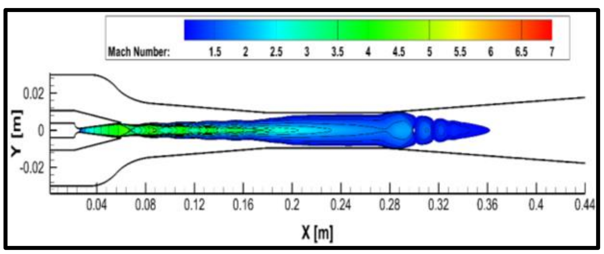
Prediction is not accurate

some parameters cannot be predicted (Temperature & Pressure)

- Secondly, CFD (computational fluid dynamic) to perform the inspection of the model to visualize the performance such as:

Visualization of shock waves, turbulences and flow separation.

All parameters can be obtained accurately.



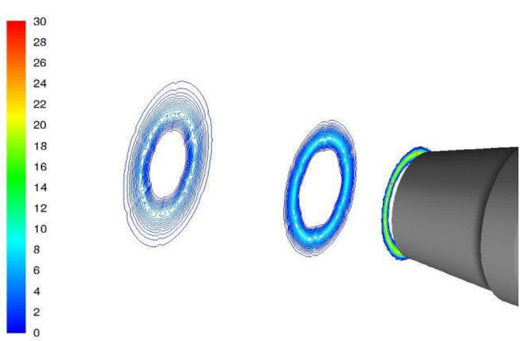
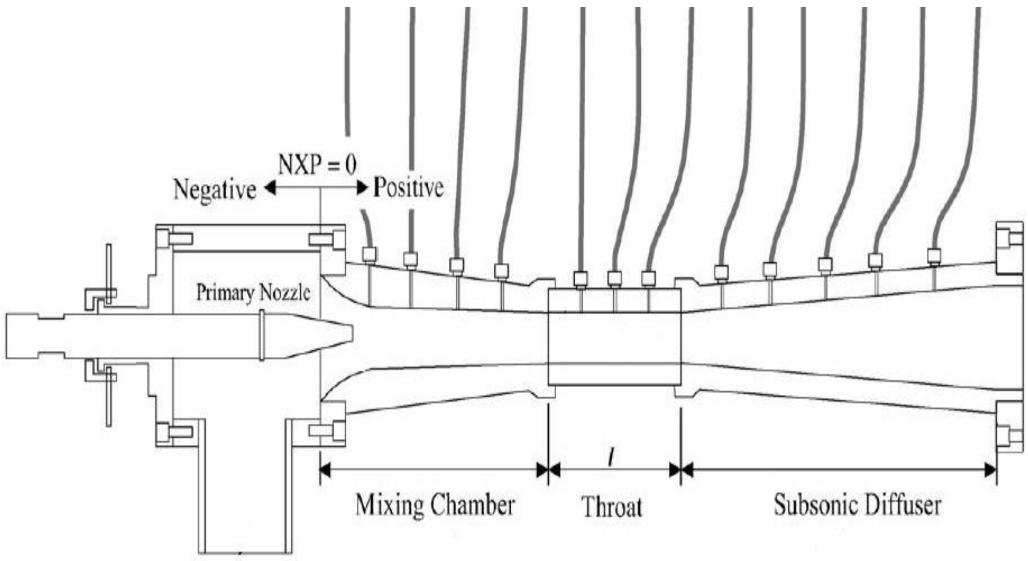


Figure 4.1: Vorticity result of the circular nozzle

 Experiment overview



Overall position of all sensors installed to the supersonic ejector in order to have high prediction of pressure flowing.

Static pressure sensors	Air-absolute pressure-high accuracy 0-16bar(primary fluid) 0-20 kpa (ejector) (Further step)
Gas bottles	3000 psi gas bottles Compressed
Set of adapters	1/8 NPT to 1⁄4 NPT
Pressure regulators	Rented
Piping system	Not purchased yet
Hoses and flanges	Standard flanges and doubled tubed hoses

- **Experiment setup:**

I. Assembly of ejector parts:

As we can see in the picture we divided the ejector into three main parts connected together using special o- rings. We can see the mixing chamber throat and diffuser. We cut them to simplify the machining process.

Figure 4.2- O-rings

II. Connection of hoses:

We connect a double tube hose that have an inner metal tube that can resist high pressure to the pipe at the primary inlet of the ejector. At the secondary inlet we connect a flange that is tied to a hose

III. Air bottle and pressure regulator:

The pressure regulator is attached to the air bottle and the hose that is connected to the primary inlet. As it shown in the figure below the pressure regulator have two gages, one is for internal pressure in the air bottles (3000 psi), and another gage to show the pressure that is regulated for the primary inlet and its limited to regulate up to (200 psi).

IV. Connecting presser sensors:

A set of static pressure sensors should be placed along the ejector to obtain a real and accurate spectrum of pressure along the ejector to see clearly flow separation, turbulences, chock waves and the mixing of fluids.

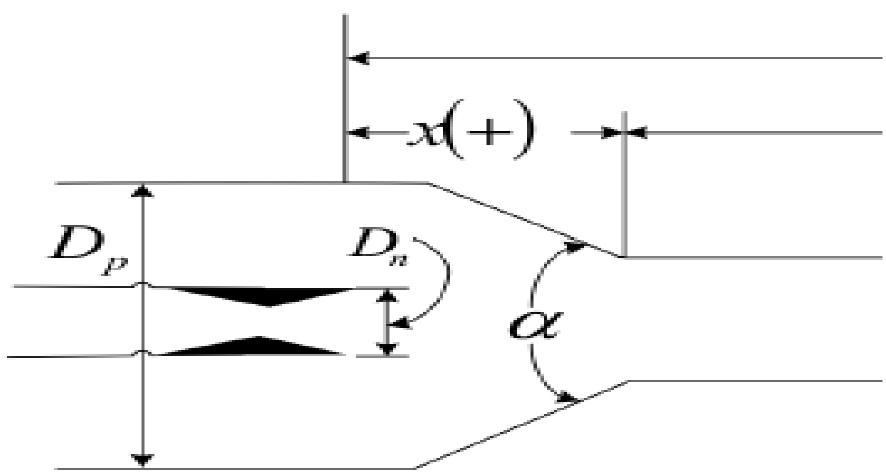
V. Start-up:

Making sure everything as aligned and connected properly, make sure the ejector is fixed in a base to ensure it wouldn't vibrate or move when the ejector is operating in high pressure, attaching the tied hose from the secondary inlet to the water reservoir.

- **Testing parameters:**

NXP effect:

NXP is the nozzle exit position where X is shown in the figure. Large NXP decreases turbulences and decreases the entrainment ratio. Small NXP decreases the velocity of the mixing fluid at the diffuser. Nozzle should be centered with the throat tube and should be cleaned



During experimental and testing approach, pressure, temperature and flow rate values may vary during the flowing inside different parts of supersonic ejector system. In contract mainly values circulating about specific measurements for instance temperature around 210C , pressure about 2 Mpa and flow rate around 6 g/s.

4.2 Results, Analysis and Discussion

Experiment goals:

There is numerus amount of objectives under testing analysis. After assembling the entire system, the concentration will be about the following: First, the value of the variation of the pressure must be concerned in order to have vacuum pressure (Suction). Second, adjusting the nozzle position so that maximum entrainment ratio is gained. Third, investigating the performance of the pressure in perspective of predictable way. Finally inspect the flow in way that doesn't across the shock waves

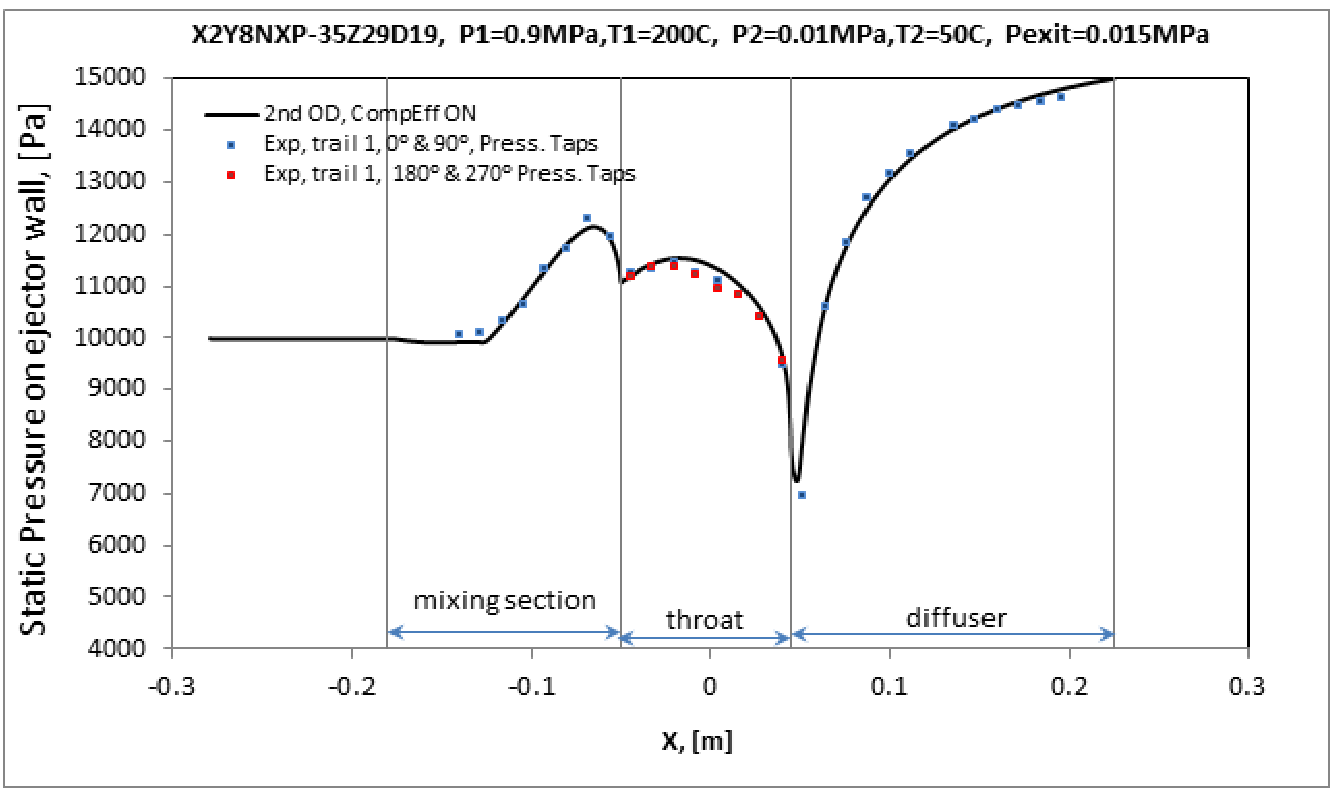


Figure 4.3 static pressure along assembled ejector

Experimental procedure

After the ejector is assembled and connected all sensors we conduct the experiment by:

We open the valve of the air bottle at 200 PSI that is connected to the primary inlet of the ejector.

Secondary we use the hose that is connected to the secondary inlet to operate the vacuum to suck the water from reservoir.

Figure 4.4: Ejector operating

Experimental pressure

Data and result:

Static pressure	Test 1	Test 2
Primary nozzle	2 Mpa	2 Mpa
Mixing chamber	0.012 Mpa	0.0119 Mpa
Throat	0.0095 Mpa	0.0096 Mpa
Diffuser	0.0146 Mpa	0.0145 Mpa

Pressure values	**readings**
Air bottle	**20 Mpa**
Water vacuum	**Atmospheric pressure**

The primary and secondary streams expand isentropically over the nozzles. Similarly, the mixture stream compresses isentropically in the diffuser. The primary also secondary fluid streams both are saturated vapor and their inlet speeds kind of negligible. Velocity of the compressed mixture exit the diffuser is also negligible.

steady isentropic expansion exponent and ideal gas behavior is expected. The integrating of the primary and secondary vapor accomplished place in the mixing chamber and it is done before the attendance of the shock wave. The boundaries of the ejector are concerned an adiabatic boundary. Friction losses are clarified in terms of isentropic efficiencies in the nozzle, diffuser, and mixing chamber. The ejector flow is single-dimensional with adjustable cross-sectional area level, and functioning at steady-state conditions. At position 1, or the NXP, the static pressure of the two flow streams is assumed to be uniform.

Chapter 5: project management

5.1 Project Plan

The team consisted of four members and were waiting for an opportunity to work together in a remarkable project. The members known each other since 2015 from the start of university journey. Every one of the members was willing to apply of their skills and mechanical knowledge into the senior project. As a result, we were all aware of each other's capabilities, strengths, skills and knowledge. Based on it, we held a thoughtful meeting before the start of the semester to vote and select a leader among us.

After several meetings with our advisor Dr. Mouhammad El Hassan, the team decided to choose "Designing of thermal driven supersonic ejector based on heat pump". We choose this particular project because it has many applications that help our vision 2030. For example, desalination of sea water, cooling/ heating cycles, and petroleum industry. So we saw the opportunity to work on this challenging project. The table (5.1) below shows a detailed process of the project along with the tasks

Table 5.1: detailed process of the project tasks

Activity	Tasks	Responsible	Start date	Due date	Days to complete
Search of a project	Select project	All team	1/1/19	6/1/19	6
Chapter1: **Introduction**	Project Definition	Nassir	6/1/19	10/1/19	4
	Determine Objectives	Saeed	6/1/19	10/1/19	4
	Project Specifications	Abdullah	6/1/19	10/1/19	4
	Applications	Abdullah	6/1/19	10/1/19	4
Chapter2: **Literature Review**	Project background	Anas	15/1/19	20/1/19	5

	Previous work	Abdullah& Anas	15/1/19	20/1/19	5
	Comparative study	Nassir & Saeed	15/1/19	20/1/19	5
Chapter3: **System Design**	Design Constraints	Abdullah	21/1/19	31/1/19	10
	Design Methodology	Saeed	21/1/19	31/1/19	10
	Product Subsystems and Components	Abdullah	21/1/19	31/1/19	10
	Implementation	Anas	21/1/19	31/1/19	10
	Engineering Standards	Nassir	21/1/19	31/2/19	10
	Design specifications & CAD	Nassir & Anas	21/1/19	10/2/19	20
	Select materials	Nassir	2/2/19	10/2/19	8
	Manufacturing process	Abdullah & Nassir	10/2/19	31/3/19	49
Midterm presentation	Making slides	Abdullah	10/3/19	21/3/19	11
Chapter4: **System Testing and Analysis**	Experimental Setup	Saeed	22/3/19	4/4/19	13
	Testing and Analysis	All team	22/3/19	4/4/19	13
	Results	All team	22/3/19	4/4/19	13
Chapter5: **Project Management**	Project Plan	Abdullah	22/3/19	31/3/19	9
	Contribution of Team Member	Nassir	22/3/19	31/3/19	9
	Project Execution Monitoring	Saeed	22/3/19	31/3/19	9
	Challenges and Decision Making	Anas	1/4/19	6/4/19	6
Chapter6: **Project Analysis**	Life-long learning	Nassir	1/4/19	8/4/19	8
	Impact of Engineering Solutions	All team	4/4/19	10/4/19	6
	Contemporary Issues Addressed	Saeed	4/4/19	10/4/19	6

Chapter7: **Conclusions and Future Recommendation**	Conclusions	Anas	12/4/19	17/4/19	5
	Future Recommendations	Abdullah	12/4/19	20/4/19	8

5.2 Contribution of Team Member

Each member was excited to be as much professional as possible and show dedication to the work. The leader was keeping a record of the all the tasks that were accomplished and advising them to the team regularly, along with the next agenda to be delivered and assigned to specific members with a deadline Nassir and Abdullah spent more efforts in the field with the manufacturing and technical side while Anas and Saeed put their hands more into the theoretical and reporting side.

5.3 Project Execution Monitoring

The members of the team meet at least once a week during the first 2 months, then meets almost every day during the last month. Everything was tracked, updated and communicated through the social App, WhatsApp or through teleconference. Every member was supportive, enthusiastic and eager to give a hand whoever is in need. We have known each other since 2015 and there is a strong chemistry between us in understanding and executing the tasks with fewer complications. Whenever there is a situation that needs an advice, the team would directly have a contact with the advisor to clear things out and move on.

5.4 Challenges and Decision Making

The team suffered during the project in many aspects. One of the issues we had was finding the right material that is efficient. Furthermore, The whole period was four months in total, including other subjects, assignments and projects that we take during the semester. On the other hand, the team managed to be positive and consistent in managing their duties and private responsibilities for the sake of making this project successful.

Another difficult that the leader having a part time job, which it required him extra efforts to make sure that this senior project is on the right way. Also, one of the team members used to live in Alahsa city, which was more that 120 Km away from PMU, so it made him under a severe pressure driving almost everyday forwards and backward.

As we are students, paying from our pockets, it was costly to some extent, especially when we realize the project may cost more than 10 thousand SR. Fortunately, the member expected a 5 thousands from the department at the beginning of the project and it was close by the end.

Lastly, even though there were lot workshops, there were several manufactures who were biased to their regular customers by giving them a faster service than us. Moreover, we have specific holes for 1 mm that need accurate machining like electrical discharge machining (EDM). It took longer time than expected from the manufacturer to accommodate our needs, thus, delaying our tasks.

5.5 Bill of Materials

Table 5.2: project budget

ITEM#	Description	Quantity	Cost
1	Fabrication of back nozzle	1	262.50
2	Front end	1	1260.00
3	Circular nozzle	1	1260.00
4	Primary pipe	1	945.00
5	Fabrication of ejector diffuser	1	1470.00
6	Fabrication of ejector throat	1	1470.00
6	Fabrication of ejector back end	1	1260.00
8	Fabrication of ejector mix	1	1622.91
9	Air Bottle	1	125.00
10	Bolt of presser ports	24	126.00
11	Hose	10	100
Total cost			9901.41

Chapter 6: Project Analysis

6.1 Life-long Learning

In this senior design project, functioning and working in a group qualified us how to gain skills and benefits such as: team work, time management, problem-solving, appropriate communication, trouble shooting and negotiating, we learned how to use our knowledge that we studied throughout our education by applying it in our project by demonstrating and proving theories wither experimentally or analytically, giving us opportunity to gain experience and skills. Furthermore, acquiring references was a hard job, because our project is sensitive and advanced, we have to be accurate so its hard to find a proper and legit references, we used google scholars engine to find books and articles related to ejectors and turbomachinery, we also used university library and e-books. Moreover, in manufacturing process the ejector was machined in lathe machine utilizing it in new manufacturing process called (CNC) computer numerical control. Additionally, in some part of our project we used EDM machine its much more accurate than normal lathe machine, discovering these processes would develop our knowledge in the field.

Software abilities:

In this senior design, out ability in using software have been enhanced. Using Microsoft office to share and present our project content in decent way to deliver it properly in a way that anyone could understand it easily, by using tables, figures, and graphs, etc..). Furthermore, we developed our engineering software skills in working with solidwoks (CAD) by making complex parts and shaping it to the desired design, CAD played an important role in describing this project.

Time Management abilities:

Increasing productivity and effectiveness would result from proper time managing, time management is essential to plan and organize our objectives to meet or finish it before deadlines by using Gant chart. Time management was highly considered, because it’s the key for a better performance to accomplish more in a shorter period of time, helping us to focus more in our objectives by giving us more free time.

Project Management:

At first, we planned for this project before this semester start with our instructor, to know more about the project aspect before initiating it. Executing this project by distributing the assigned tasks equally for each member in our group to be suitable for us. The giving tasks and responsibilities for each member was related his interests to work his best on it, also to enhance his experience, all tasks were known and identified by each of us to gain better knowledge about our project. Setting regular weekly meeting with our advisor, getting feedback to follow up our tasks, sometimes there is an extra meeting for an emergency matter when we face a dead end or an issue, fixing it and to come up with a reasonable solution.

Impact of engineering solution:

The ejector has many advantages compered to compressors and vacuum pumps in economic and environmental perspective. The ejector can utilize thermal energy from different free or renewable sources such as waste heat, geo-thermal, and solar collector that will eliminates the use of electricity. The working fluid in the ejector usually is water or air where it is the most environmentally friendly substance. The ejector does not require a high capital or high maintenance costs since the ejector design doesn't contain a moving part or doesn’t need lubricants, therefore the ejector considered as highly reliable devices.

6.2 Impact of engineering solution

The ejector has many advantages compered to compressors and vacuum pumps in economic and environmental perspective. The ejector can utilize thermal energy from different free or renewable sources such waste heat, geo-thermal, and solar collector that will eliminates the use of electricity. The working fluid in the ejector usually is water or air where it is the most environmentally friendly substance. The ejector does not require a high capital or high maintenance costs since the ejector design doesn't contain a moving part or doesn’t need lubricants, therefore the ejector considered as highly reliable devices.

6.3 Contemporary Issues Addressed

Petrol and gas manufacture - seeking, providing and transporting the natural gas. During these processes, they are observing a real challenge with natural gas. The gas usually mixed with significant quantities of water and others unwanted solid particles as we call it impurities. Moreover, these unwanted particles can lead to several serious troubles during expansion operation of natural gas, with presence of these particles it can cause corrosion, excessive pressure drop, hydrate, reducing in its heating value and dropping in the gas transmission efficiency. However, the entire gas planet in Gulf Cooperation Country, in specific, Saudi Arabia face a huge challenge with removing gas impurities in gas plants. Saudi Aramco filter the gas by utilizing pre-filters, filters and chemical treatment which will have detrimental effect in the economical aspect in very expensive way because, filters needs to be replaced from one period to another also the chemical have to be imported from outside the kingdom. By using a chemical treatment, plants waste will be increase more and more which that hurt the environment. Most of Gulf Cooperation Country get use gas as power source by operating gas plant which need to consider all of these factors.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

In conclusion we found out that integrating two different fluids, cause vacuum flow or on other word suction, due to the variation of the flowing pressure. Moreover, using a steam as primary fluid, can reach the system up to 5 in Mach No perspective. Utilization of stainless steel can withstand extreme internal pressure. Adjusting the rounded nozzle may extremely contributing of entrainment ratio. Regulate the angle between primary and secondary inlet, have been successfully enhance the entrainment ration. A complete prevention of fluids infiltration due to a successful assemble using O-rings. Furthermore, using hydric flexible tubes can deliver high pressure under safety conditions. As the pressure increase the vacuum will increase proportionally and vice versa. In this project, we have learned many great aspects of engineering execution such as understanding of engineering standard and develop our engineering software like Solidwork (CAD). Moreover, teamwork, decision-making, and team managing has improved our communication skills. Furthermore, we learned how to woke under pressure. This experience has taught us many great things that will help us in our future careers.

7.2 Future Recommendations

Below list of important points should be taken in consideration for whom going to continue in our project:

- Next team should choose the field where the will implement the principle of ejector in, as an example refrigeration system, water desalination, or oil distillation.
- Next team should use pressure sensors in all the holes along the ejector body to analyses and study the pressure different through the ejector.

- Next team should adjust the position of the nozzle to analyze the best position where the entrainment ratio is optimum.
- Next team should design different nozzles with different diameters to study the effect of changing nozzle’s diameter the pressure and velocity of the primary fluid.
- Next team should design chevrons nozzle in order to observe the changing of Vorticity therefore changing in impact of entrainment ratio.
- Next team should test the ejector with different working fluid to enhance the efficiency.

References:

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Appendix A: Progress Reports

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2019
PROJECT TITLE	Supersonic Ejector		
SUPERVISORS	Mouhamad EL Hassan		

Month: February

ID Number	Member Name
201502929	Abdullah H Albaheli
201501005	Nassir A Albaijan
201502942	Anass M Alomair
201402965	Saeed S Alzahrani

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	Abstract & Objectives	Saeed	98%	✓
2	Background	Anass	98%	✓
3	Introduction	Abdullah	98%	✓
4	Literature Review	Nassir	98%	✓

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	Design Prototype	Abdullah
2	Conduct Calculations	Saeed
3	Create the Drawings	Nassir
4	Material Sections	Anass

- **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	Abdullah H Albaheli	3.5	3	3.5	3.5
2	Nassir A Albaijan	3	3.5	3.5	3.5
3	Anass M Alomair	3.5	3.5	3	3.5
4	Saeed S Alzahrani	3.5	3.5	3.5	3

Comments on individual members

Name	Comments
Abdullah H Albaheli	Excellent work
Nassir A Albaijan	nice work
Anass M Alomair	Good participation
Saeed S Alzahrani	Motivated Student.

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	**ACADEMIC YEAR:**	2019
PROJECT TITLE	Supersonic ejector		
SUPERVISORS	Mouhamad EL Hassan		

Month: March

ID Number	Member Name
201502929	Abdullah H Albaheli
201501005	Nassir A Albaijan
201502942	Anass M Alomair
201402965	Saeed S Alzahrani

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	Experimental Setup, Sensors and data acquisition system	Abdullah	98%	✓
2	Analytical Results, Analysis	Saeed	97%	✓
3	Project Plan	Anass	96%	✓
4	Challenges and Decision Making	Nasser	98%	✓

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	**Manufacturing process**	Abdullah & Saeed
2	**Assemble & shakedown system**	Anass & Nasser
3	**Testing And analyzing the system**	Nasser & Saeed

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	Abdullah H Albaheli	4	4	4	4
2	Nassir A Albaijan	4	4	4	4
3	Anass M Alomair	4	4	4	4
4	Saeed S Alzahrani	4	4	4	4

Comments on individual members

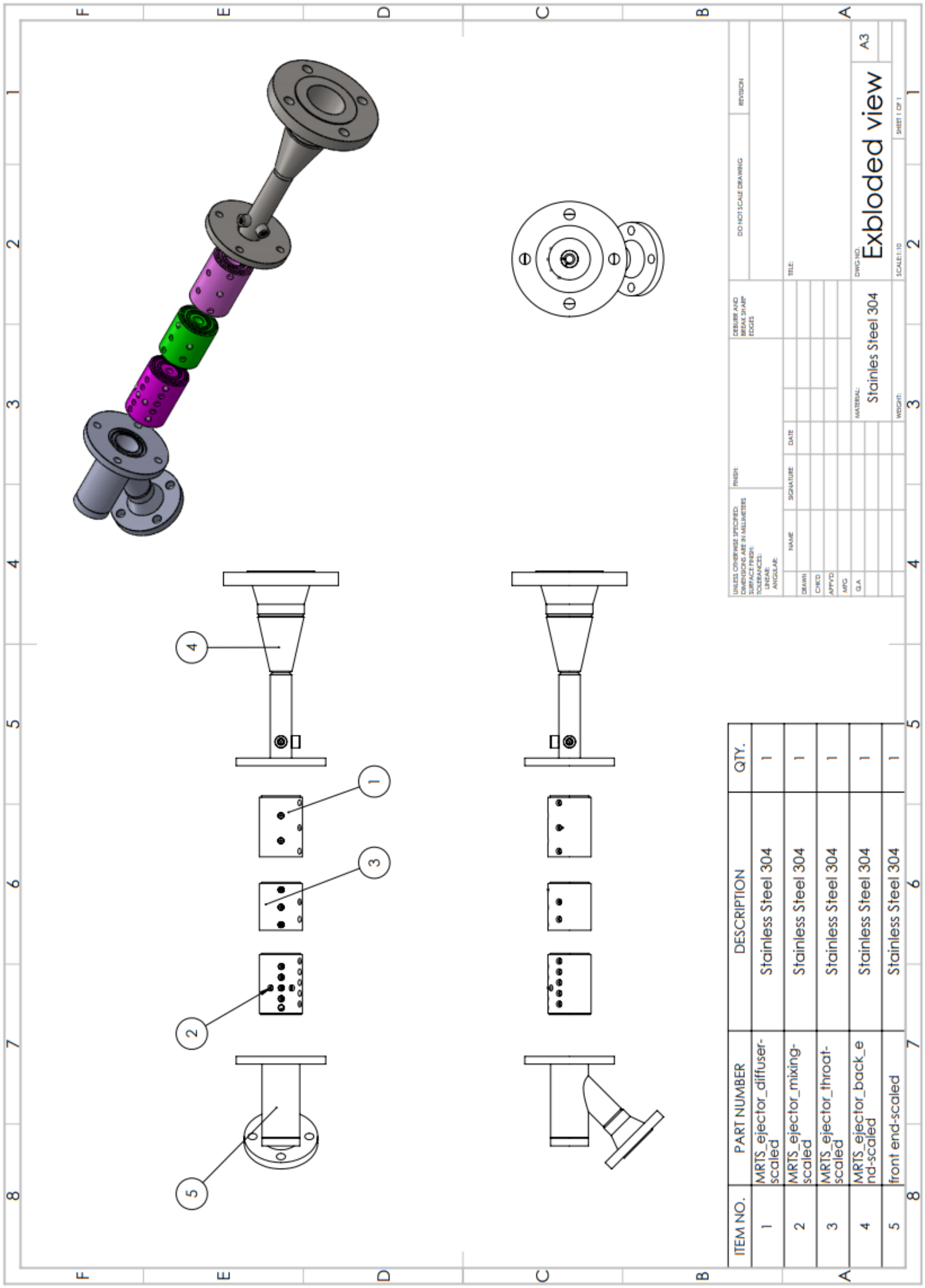
Name	Comments
Abdullah H Albaheli	Good job
Nassir A Albaijan	Good participation
Anass M Alomair	Cooperated Student
Saeed S Alzahrani	Motivated Student

Appendix B: Engineering Standard

Grade	304
Carbon (C)	0.08
Manganese (Mn)	2.00
Silicon (Si)	1.00
Phosphorus (P)	0.045
Sulphur (S)	0.030
Chrome (Cr)	18.0 20.0
Molybdenum (Mo)	--
Nickel (Ni)	8.0 11.0
Nitrogen (N)	--

Grade	304
Tensile Hardness Strength (MPa) min	515
Yield Strength 0.2% Proof (MPa) min	205
Elongation (% in 50mm) min	40

Appendix C: CAD drawing and Bill



Page No.: 1

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FOR METAL & CHROME PLATING
C. R. 2050028691
VAT # 310178251800003

مؤسسة الخضرية لخراطة
وطلاء المعدات بالكروم
س. ت ٢٠٥٠٠٢٨٦٩١
الرقم الضريبي ٣١٠١٧٨٢٥١٨٠٠٠٠٣

ص. ب ١١٣٤ – الدمام ٣١٤٣١ – طريق سريع الدمام الجبيل – المملكة العربية السعودية – تلفون : ١٣٧٢ ٨٢١ ٠١٣ / ٠٤٨٣ ٨١٨ ٠١٣ – فاكس : ٠٢٧٦ ٨٢٢ ٠١٣
P. O. Box 1134 - Dammam 31431 - Dammam Jubail Highway - Saudi Arabia - Tel.: 013 821 1372 / 818 0483 - Fax: 013 822 0276
E-mail: accounts@aktc.sa.com - mail@aktc.sa.com - aktc_sa@hotmail.com :البريد الإلكتروني

VAT INVOICE
فاتـــورة ضريبة

Customer Name: CASH CASH CUSTOMER	اسم العميل:	Invoice No. رقم الفاتورة	1801784
		Invoice Date: تاريخ الفاتورة	11-04-2019

Purchase Order No. رقم أمر الشراء	Payment Terms شروط الدفع	Due Date تاريخ الاستحقاق	Date of Supply تاريخ التسليم
NASER ALBUYAN	CASH ON DELIVERY	11-04-2019	11-04-2019

رقم SI #	رقم المنتج Product Code / مواصفات المنتج Description	الكمية Quantity	سعر الوحدة Unit Price	الإجمالي السعربدون الضريبة Total Price Excl. of VAT	الضريبة ٪ VAT %	الضريبة VAT Amount	مجموع السعر Total Price (SR)
1	FABRICATION OF BACK NOZZLE	1 PC	250.00	250.00	5	12.50	262.50
2	FRONT END SCALED	1 PC	1,200.00	1,200.00	5	60.00	1,260.00
3	CIRCULAR NOZZLE 1.5 MM	1 PC	1,200.00	1,200.00	5	60.00	1,260.00
4	PRIMARY PIPE - FRONT END SCALED WILL BE SUPPLIED IN TOO PART AND WELDED TOGETHER & ALL MATERIAL IS SS 304.	1 PC	900.00	900.00	5	45.00	945.00
5	FABRICATION OF EJECTOR DIFFUSER	1 PC	1,400.00	1,400.00	5	70.00	1,470.00
6	FABRICATION OF EJECTOR THROAT	1 PC	1,400.00	1,400.00	5	70.00	1,470.00
7	FABRICATION OF EJECTOR BACK END	1 PC	1,200.00	1,200.00	5	60.00	1,260.00
8	FABRICATION OF EJECTOR MIX	1 PC	2,000.00	2,000.00	5	77.28	1,622.91
	D-PAYMENT 2000/- DTD 12/03/19 + 4000/- 25/03/19 + 900 (2/4/19)				Discount		454.37

PAID
-- APR 2019
AL-KHODHARIYAH TURNERY CO

Authorized Signature المفوض بالتوقيع	Total Amount Before VAT	المجموع قبل الضريبة	9,095.63
	VAT Amount 5 %	قيمة الضريبة المضافة ٥٪	454.78
	Total Invoice Amount	المجموع النهائي	9,550.41

Received by: المستلم : Job Order No. 28561 OFFICE Sales Rep.: مندوب المبيعات:

Name: الاسم:	Signature: التوقيع:	Date: التاريخ:	Company Stamp الختم

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مؤسسة الخضرية لخراطة
وطلاء المعدات بالكروم

سجل تجاري ٢٠٥٠٠٢٨٦٩١
ص.ب ١١٣٤ - الدمام ٣١٤٣١
تلفون : ٨١٨٠٤٨٣ / ٨٢١١٣٧٢ / ٨١٨٠٤٨٥ (٩٦٦١٣+)
فاكس : ٨٢٢٠٢٧٦ (٩٦٦١٣+)
البريد الالكتروني : mail@aktc.sa.com
البريد الالكتروني : aktc_sa@hotmail.com
الدمام - الجبيل السريع - المملكة العربية السعودية

JOB COMPLETION / DELIVERY NOTE

Delivery Note	1702243	Date	11-04-2019
Job Order Number	28561	Sales Ref.	AKTC/3683/19

Customer Name	CASH CUSTOMER		CASH
Shipping Address	Dammam, Saudi Arabia		
PO No.	NASER ALBUYAN	Vendor ID	

Kindly receive the following items in good condition.

S#	Product ID	Description	Quantity	UOM
1	2	FABRICATION OF EJECTOR DIFFUSER	1.00	PC
2	2	FABRICATION OF EJECTOR THROAT	1.00	PC
3	2	FABRICATION OF EJECTOR BACK END	1.00	PC
4	2	FABRICATION OF EJECTOR MIX	1.00	PC
Total			4.00	

Materials were received & accepted.

RECEIVED BY

Name :
Signature :
Date :
Company Stamp :

DELIVERED BY

Name : ....
Signature.:..................................
Date : ....

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E-mail : mail@aktc.sa.com
E-mail : aktc_sa@hotmail.com
Dammam - Jubail Highway - Saudi Arabia

مؤسسة الخضرية لخراطة
وطلاء المعدات بالكروم

سجل تجاري ٢٠٥٠٠٢٨٦٩١
ص.ب ١١٣٤ - الدمام ٣١٤٣١
تلفون : ٨١٨٠٤٨٣ / ٨٢١١٣٧٢ / ٨١٨٠٤٨٥ (١٣ ٩٦٦+)
فاكس : ٨٢٢٠٢٧٦ (١٣ ٩٦٦+)
البريد الالكتروني : mail@aktc.sa.com
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الدمام - الجبيل السريع - المملكة العربية السعودية

QUOTATION

CASH
CASH CUSTOMER

AKTC No : 3683

DATE : 11-04-2019

KIND ATTN .	MR. NASSIR A ALBAIJAN (PMU)
SUBJECT	EJECTOR PARTS

DEAR SIR ,
WE ARE PLEASED TO SUBMIT OUR COMMERCIAL OFFER FOR THE BELOW MENTIONED ITEM ALL IN ACCORDANCE WITH THE SPECIFICATION AS FOLLOWING

S #	Code	Description	Units	Qty	Price	Total
1	2	FABRICATION OF EJECTOR DIFFUSER	PC	1.00	1,400.00	1,400.00
2	2	FABRICATION OF EJECTOR THROAT	PC	1.00	1,400.00	1,400.00
3	2	FABRICATION OF EJECTOR BACK END	PC	1.00	1,200.00	1,200.00
4	2	FABRICATION OF EJECTOR MIX	PC	1.00	2,000.00	2,000.00

NOTES :

TOTAL PRICE BEFORE VAT :	6,000.00
DISCOUNT :	
VAT (5%) :	300.00
TOTAL PRICE:	6,300.00

General Terms

QUOTATION VALIDITY	DELIVERY TIME	PAYMENT TERMS
28-04-2019		CASH

WITH BEST REGARDS.

KHALID AL- BOSHI (GENERAL MANGER)

OFFICE Salesman

DILEEP KUMAR Prepared By

AL-KHODHARIYAH TURNERY EST.
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C.R. 2050028691
P.O. Box 1134, Dammam 31431
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سجل تجاري ٢٠٥٠٠٢٨٦٩١
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تلفون : ٨١٨٠٤٨٣ / ٨٢١١٣٧٢ / ٨١٨٠٤٨٥ (١٣ ٩٦٦+)
فاكس : ٨٢٢٠٢٧٦ (١٣ ٩٦٦+)
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الدمام - الجبيل السريع - المملكة العربية السعودية

JOB COMPLETION / DELIVERY NOTE

Delivery Note	1702242	Date	11-04-2019
Job Order Number	28710	Sales Ref.	

Customer Name	CASH CUSTOMER	CASH
Shipping Address	Dammam, Saudi Arabia	
PO No.	NASSR A ALBAIJAN	Vendor ID CASH

Kindly receive the following items in good condition.

S#	Product ID	Description	Quantity	UOM
1	2	FABRICAITON OF BACK NOZZLE	1.00	PC
2	2	FRONT END SCALED	1.00	PC
3	2	CIRCULAR NOZZLE 1.5 MM	1.00	PC
4	2	PRIMARY PIPE - FRONT END SCALED WILL BE SUPPLIED IN TOO PART AND WELDED TOGETHER & ALL MATERIAL IS SS304	1.00	PC
Total			4.00	

Materials were received & accepted.

RECEIVED BY

Name :
Signature :
Date :
Company Stamp :

DELIVERED BY

Name : ....
Signature.:.................................
Date : ....

Page No.: 1

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Dammam - Jubail Highway - Saudi Arabia

مؤسسة الخضرية لخراطة
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سجل تجاري ٢٠٥٠٠٢٨٦٩١
ص.ب ١١٣٤ - الدمام ٣١٤٣١
تلفون : ٨١٨٠٤٨٣ / ٨٢١١٣٧٢ / ٨١٨٠٤٨٥ (+٩٦٦ ١٣)
فاكس : ٨٢٢٠٢٧٦ (+٩٦٦ ١٣)
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البريد الالكتروني : aktc_sa@hotmail.com
الدمام - الجبيل السريع - المملكة العربية السعودية

QUOTATION

CASH
CASH CUSTOMER

AKTC No : 3684

DATE : 11-04-2019

KIND ATTN.	MR. NASSIR A ALBAIJAN (PMU)
SUBJECT	PARTS

DEAR SIR ,
WE ARE PLEASED TO SUBMIT OUR COMMERCIAL OFFER FOR THE BELOW MENTIONED ITEM ALL IN ACCORDANCE WITH THE SPECIFICATION AS FOLLOWING

S #	Code	Description	Units	Qty	Price	Total
1	2	FABRICAITON OF BACK NOZZLE	PC	1.00	250.00	250.00
2	2	FRONT END SCALED	PC	1.00	1,200.00	1,200.00
3	2	CIRCULAR NOZZLE 1.5 MM	PC	1.00	1,200.00	1,200.00
4	2	PRIMARY PIPE - FRONT END SCALED WILL BE SUPPLIED IN TOO PART AND WELDED TOGETHER & ALL MATERIAL IS SS304	PC	1.00	900.00	900.00

NOTES :

TOTAL PRICE BEFORE VAT :	3,550.00
DISCOUNT :	
VAT (5%) :	177.50
TOTAL PRICE:	3,727.50

General Terms

QUOTATION VALIDITY	DELIVERY TIME	PAYMENT TERMS
28-04-2019		CASH

WITH BEST REGARDS.

KHALID AL- BOSHI
(GENERAL MANGER)

OFFICE
Salesman

DILEEP KUMAR
Prepared By