

## CFD Analysis of Nozzle Exit Position Effect in Ejector Gas Removal System in Geothermal Power Plant

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### Abstract

The single stage ejector is used to extract the Non Condensable Gas (NCG) in the condenser using the working principle of the Venturi tube. Three dimensional computational simulation of the ejector according to the operating conditions was conducted to determine the flow in the ejector. Motive steam entering through the convergent – divergent nozzle with increasing flow velocity so that the low pressure exist around the nozzle. Comparison is done also in a two dimensional simulation to know the differences occurring phenomena and flow inside ejector. Different simulation results obtained between two dimensional and three dimensional simulation. Reverse flow which occurs in the mixing chamber made the static pressure in the area has increased dramatically. Then the variation performed on Exit Nozzle Position (NXP) to determine the changes of the flow of the NCG and the vacuum level of the ejector.

**Keywords:** Ejector, NCG, CFD, Compressible flow.

### 1. INTRODUCTION

Geothermal energy produced high pressure hot steam that could turn the turbine as the main source of geothermal power plant. The steam that produced by the production well consists of substances and also moisture which were different for each well. One of the gas characteristics that contain in geothermal source is Non Condensable Gas (NCG). Which why when condensation steam came out of the turbine, NCG gathered in condenser that made the condenser vacuum pressure decrease and made the turbine work come down.

Geothermal systems have the operating conditions for the system to run optimally. Geothermal condenser works on vacuum pressure -0.69 Barg. When the pressure in the condenser increases, the performance of the turbine will decrease. As seen in the T-s diagram in Figure 1, work produced turbines will decrease, so that the total efficiency of geothermal power plants will decrease as well. Vacuity of condenser must be kept constant because it will help the performance of the turbine. Large enthalpy difference in the

turbine will generate more power. Therefore NCG accumulated in the condenser must be extracted in order to keep the pressure in the condenser.

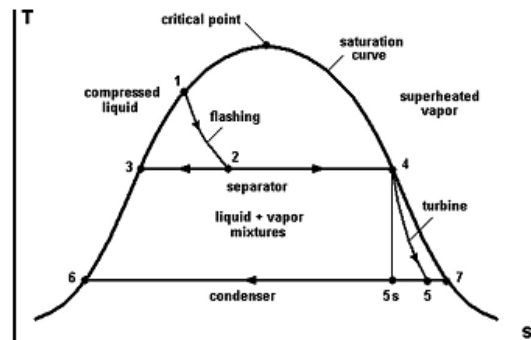


Figure 1. T-s Diagram for Geothermal Power Plant

Geothermal power plant used Gas Removal System (GRS) for extract NCG from the condenser. One of the main GRS components was Steam Jet Ejector as the first step of extraction. Ejector used Venturi tube principle; it used geothermal energy as NCG extractor. The pressure that given by the geothermal energy affecting the suction ejector pressure, so the ejector only worked at some inlet nozzle condition.

When the outlet ejector condition was unknown, it was necessary to use computational analysis. To get the properties, simulation was conducted to consider ejector operational condition by applying the exist properties. The changes of the property based on little relative time means that the ejector condition was considered steady. Motive steam was assumed in vapor state because the NCG that contained inside only 1% and the rest was CO<sub>2</sub>, because 95% NCG was CO<sub>2</sub>. There was no leak in the system; the analysis used fluid mechanics and ignoring thermodynamics sides. The observe component was ejector 65% duty as operated in real condition.

### Compressible Flow

This is a flow in which there are significant or noticeable changes in fluid density. Just as invisidfluids do not actually exist, so in incompressible fluid do not actually exist. The consequences of compressibility are not limited simply to density changes. Density changes mean that a significant compression or expansion work exist on a gas, so the thermodynamic state of the fluid will change, meaning that in general all property like temperature, internal energy, entropy, and so on can change. Density changes create a mechanism for exchange of energy between mechanical and the termal internal energy

In compressible flow. All properties ( $p, T, \rho, u, h, s, V$ ) may be changing as the flow proceeds. Reference conditions that can be used to relate conditions in flow from point to point were necessary. Stagnation properties ( $p_0, T_0, \rho_0$ ) is used to actual properties. K is the ratio of spesific heats and M is the Mach

number of the fluid flow. This equation below is for determining local isentropic stagnation properties:

$$\frac{p_0}{p} = \left[ 1 - \frac{k-1}{2} M^2 \right]^{k/(k-1)} \quad (1)$$

$$\frac{T_0}{T} = 1 - \frac{k-1}{2} M^2 \quad (2)$$

$$\frac{\rho_0}{\rho} = \left[ 1 - \frac{k-1}{2} M^2 \right]^{1/(k-1)} \quad (3)$$

In deriving the Navier-Stokes equations for incompressible Newtonian fluids, the velocity divergence,  $\nabla v = 0$ , was explicitly used to obtain the most general form of a symmetric stress tensor that is linear in the velocity gradients. But when flow velocities become a finite fraction of the velocity of sound, it is as discussed before no longer possible to maintain the simplifying assumption of even effective incompressibility. For truly compressible fluids the divergence is non-vanishing, and the simple divergence condition was simplified and replaced by the continuity equation. Inserting the modified stress tensor into Cauchy's equation of motion then:

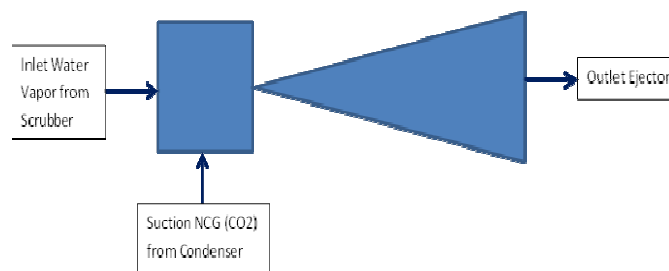
$$\rho \left( \frac{\partial v}{\partial t} + (v \cdot \nabla) v \right) = f - \nabla p + \eta \nabla^2 v + \left( \zeta + \frac{1}{3} \eta \right) \nabla (\nabla \cdot v). \quad (4)$$

## Ejector

Ejector in Figure 2 worked with Venturi principle. The motive steam was expanding with a nozzle to gain suction pressure in suction part. The pressure of the steam was processed to be kinetic energy. The motive steam flow velocity reached supersonic when leaving convergence-divergence nozzle so the pressure was very low that made  $\text{CO}_2$ , which mostly was NCG, sucked in the ejector. In mixing chamber, the steam was mixed by  $\text{CO}_2$  and made the pressure increase a slightly. In subsonic diffuser part, the mixed flow velocity was decreased so the pressure was increased in the outlet.

As shown in Figure 2, the ejector parts are:

- Convergence-divergence Nozzle
- Suction Chamber
- Mixing Chamber
- Throat Ejector
- Diffuser Ejector



**Figure 2.** Ejector Diagram

Based on Safarudin (2011) the CO<sub>2</sub> flew from suction part was because the condition of suction ejector had higher static pressure than inside the mixing chamber. This condition was the result of compression effect in nozzle outcome flow which affects the amount of nozzle main flow. In suction pressure condition which conditioned steady for all variation with -0.69 Barg, the increasing of inlet nozzle pressure caused the forming of main motive steam faster. It was because the effect of nozzle outcome flow as in expanded condition, had velocity that almost supersonic, with larger fluctuative pressure condition.

## **2. RELATED WORKS**

In previous work, there is a research which performed 2D CFD simulation in order to obtain the pressure distribution along the ejector (Safarudin, 2011). The 2D simulation input of the simulation will based this research input and those results will be compared with this research's result which will perform the 3D CFD simulation.

In 2D simulation, most of the motive steam will directly flow to the downstream. There is no 3D effect in the flow, so the swirl of the flow was not significant. The flow phenoma will determine the pressure distribution along the ejector, so this research will compare the pressure distribution between 2D and 3D CFD simulation.

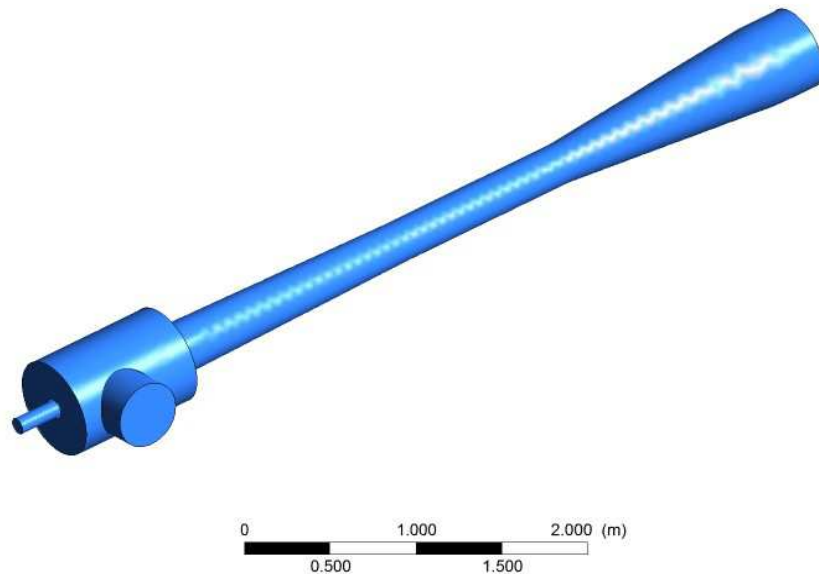
## **3. ORIGINALITY**

The research was conducted to look at phenomena that occur in motive steam and NCG and the performance of the ejector shown with a vacuum on the suction side of the ejector. The object of research is an ejector on Gas Removal System GPP IV. Kamojang. Required simulated computationally efficient to run ejector using existing operating data. In the industrial world it is often used as an option to determine the performance of the components were observed without terminating the system running. So the savings in terms of cost and time to do. On this project performed at the ejector 3D simulations to determine the flow that occurs in the ejector. Using the operating data as initial data simulation. Simulations were approached with the actual conditions by describing the geometry in full scale. Variations performed on this project aims to see whether there was an increase performance of ejector is shown by the decrease in pressure at the suction. The variables are changed on the length of extension so the nozzle exit position change which will influence the pressure at the outlet of suction.

## **4. SYSTEM DESIGN**

The simulation using Computational Fluid Dynamic (CFD) was commonly used to predict the outcome of a project. In this research, the simulation of ejector research object used is CFD three dimensional with actual operating geometry of the ejector. The research object was made by the geometry ejector that given in the manual book (2) GRS PT Pertamina

Geothermal Energy as seen in the Figure 3. Modeling method was set to get the result which almost like the operational condition, the operational data should be valid so it would produce small percentage of error. The CFD modeling input data was given as shown in the Table 1.



**Figure 3.** Geometry Ejector

**Table 1.** Simulation modelling method

<b>Models</b>	
Viscous	: Realize k- $\epsilon$
Species	: Species Tansport - No Reaction
<b>Boundary conditions</b>	
Inlet Ejector	: Pressure inlet
Suction Ejector	: Mass flow inlet
Outlet Ejector	: Pressure outlet
<b>Solution Methods</b>	
Pressure Velocity Coupling	: Simple
Pressure	: Standart
Momentum	: First Order Upwind
Turbulent Kinetic Energy	: First Order Upwind
Turbulent Dissipation Rate	: First Order Upwind
Energy	: First Order Upwind

The input boundary condition used operational data which taken on July 21<sup>th</sup> to 27<sup>th</sup> 2014 in Kamojang geothermal powerplant unit IV. The objective of the CFD simulation was to know the unknown properties. Otherwise to watch the flown phenomenon in the ejector when it was operate are used to make it into basic data to increase the work of ejector. The simulation process was repeated until suitable with the condition according to Table 2. Unfortunately, there is no experimental research to verified these simulations, so the verification and validation of simulation

were conducted by comparing the simulation results and the operational conditions of the powerplant as shown in Table 2.

**Table 2.** Comparison between operation conditions with CFD Simulation

	Actual Conditions	CFD Simulation
mass flow inlet nozzle (kg/s)	1,315	1,389
mass flow inlet suction (kg/s)	0,6637	0,6637
Inlet static pressure (Pa)	1.085.675,1	1.083.485,5
Suction static pressure (Pa)	-0,69	-0,6876
Outlet static pressure (Pa)	-	-0,475

Fluid material modeling was used to get simulation output that close to observation data which shown in the Table 3. The value of heat capacity and dynamic viscosity from water-vapor and CO<sub>2</sub> was based from journal [1] which has the same material and basic observation. Otherwise, the density of water-vapor was specially used to get the right modeling. Modeling of compressible flow of water-vapor was conducted in order to get the best simulation results. There are no references about modeling the compressible flow. Simulations performed repetitive to get the right CFD setting that the results of the simulation can be convergent. The setting performed in control solution of the simulation. Setting the wrong simulation will cause divergent result. Fluid materials modeling that chosen are shown in Table 3.

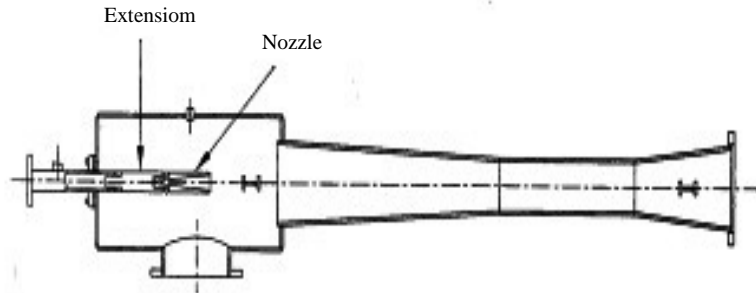
**Table 3.** Fluid Material Modelling

Working fluid	Water-vapor (H <sub>2</sub> O)	NCG (CO <sub>2</sub> )	Mixture template
Density (kg/m <sup>3</sup> )	Compressible liquid	1.7878 (default)	volume weighted mixing law
Heat Capacity Cp. (j/kg-K)	2786.19	856.99	Mixing - law
Viscosity din. (kg/ms)	1.5221e-05	1.37e-05	Mixing - law

The CFD modeling method simulation data was used to get variation on NXP ejector. The objective was getting alternative geometry of ejector so the ejector performance could increase, which is vacuity of ejector was increased, and then the NCG will be more extracted from the condenser. The variation was done by making extension longer from ejector which places like in Figure 4. Replacement nozzle extension requires low cost and easy to do. So it can be performed at any during maintenance. In addition variation of extension nozzle length has also been performed by other research. Extension in operational condition had 6" long. The variations of NXP ejector are shown in Table 4.

**Table 4.** NXP Ejector Variations

Variation	Extension Length
Variation 1	76,2 mm (3")
Variation 2	228,6 mm (9')
Variation 3	304,8 mm (12")

**Figure 4.** Extension position in the ejector

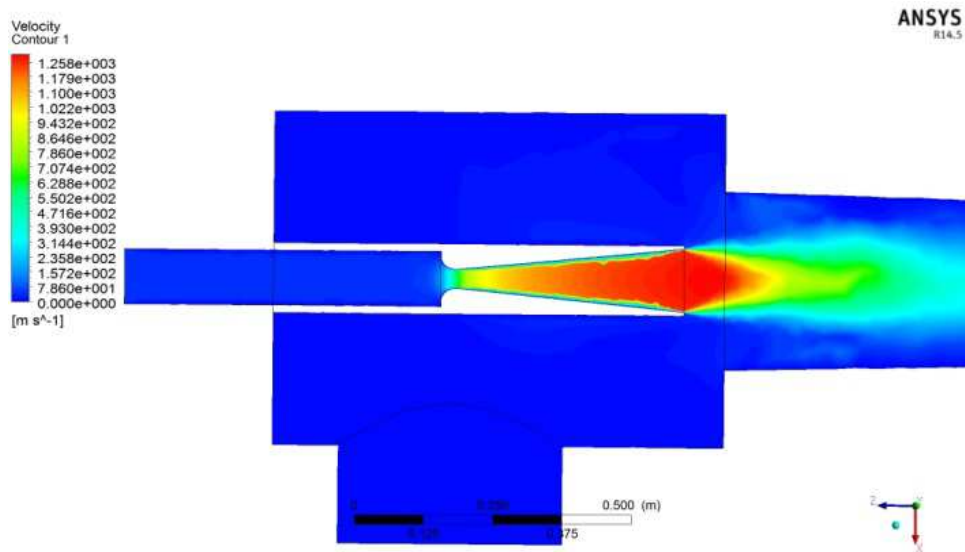
The input properties material of working fluid and the definition of input and output fluid flow boundary as shown in Table 5 which shown the simulation input for inlet ejector pressure with 10.8 Barg.

**Table 5.** Simulation's input

	Inlet Ejector	Suction Ejector	Outlet Ejector
Boundary Condition	Pressure inlet	Mass flow inlet	Perssure outlet
Static Pressure (Pa)	1.085.675	16.000	To be varied
Mass Flow (Kg/s)	-	0,663	300 (default)
Temperature (K)	467,65	316,31	
Turbulence model	Intencity& DH	K and Epsilon	K and Epsilon
Hydrolic Diameter (m)	0,102	-	-
Turb. Intencity	2	-	-
Turb. Kin. Energy	-	1 (default)	1 (default)
Turb. Dissipation	-	1 (default)	1 (default)

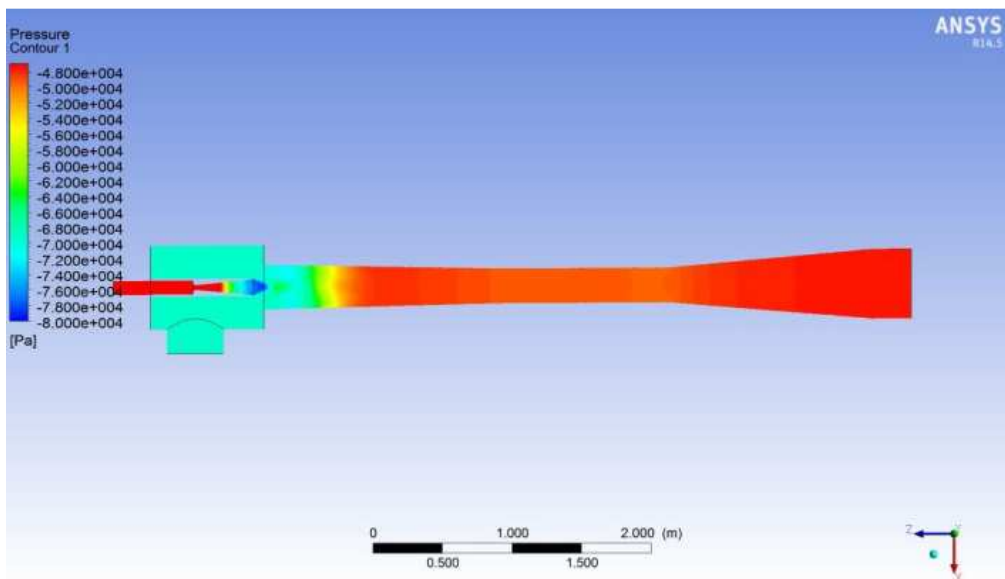
## 5. EXPERIMENT AND ANALYSIS

Expansion motive steam proceed by nozzle ejector was done by increasing the flow velocity into supersonic which shown in Figure5. The increasing occured in the inlet ejector with 47.8 m/s until the outlet ejector outburst had 1200 m/s. It was occur because the function of convergence-divergence ejector. The nozzle mostly used in ejector to convert the velocity of the flow. The effect caused the pressure around nozzle decreasing even smaller than in suction ejector which suitable with Venturi tube principle.



**Figure 5.** The velocity contour in nozzle ejector

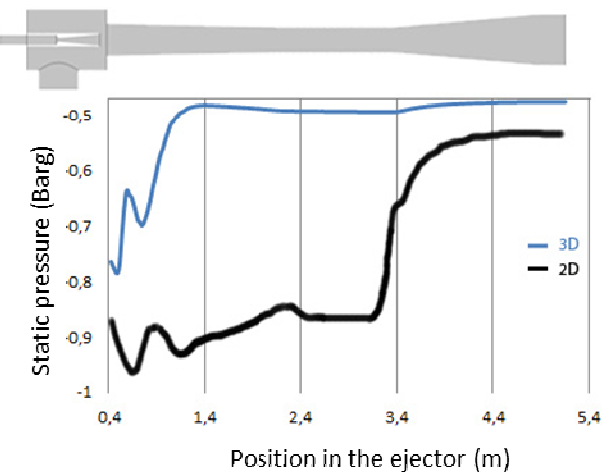
The expansion pressure effect caused NCG flow from suction into ejector because the static pressure was higher than in the mixing chamber ejector which was -0.78 Barg. It also shown in Figure6, which the outlet nozzle flow had lower static pressure then in the suction ejector. The static suction pressure was kept to be steady in -0.69 Barg which was the constant pressure in condenser. Static pressure contour happened until the mixing chamber, which was place of motive steam and CO<sub>2</sub> mixed. In throat until ejector diffuser part the static pressure distribution still had small changes. It was because the difference between mixing chamber and diffuser ejector surface area, it made the mixing flown has very small velocity changes.



**Figure 6.** Static pressure contour

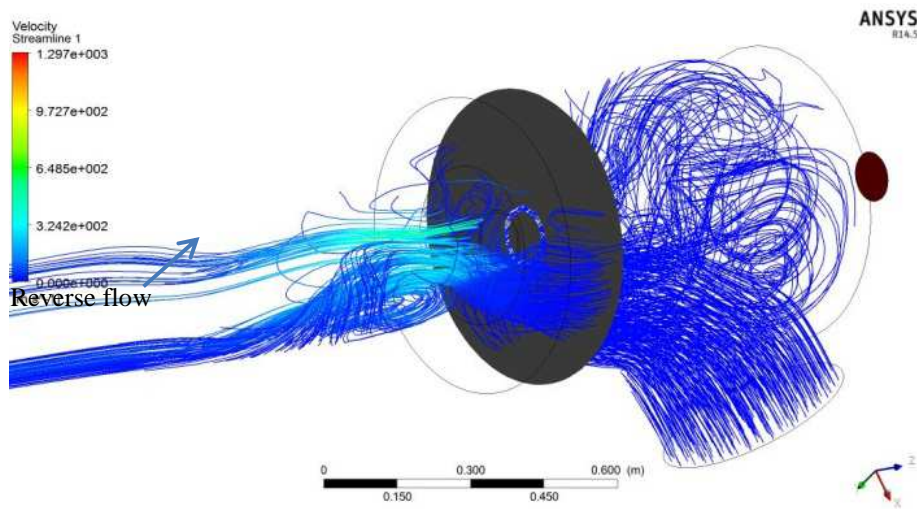


The comparison was done in the literature with the same observation object but with different simulation method, which used two dimensional method as shown in Figure 7. The static pressure had been plot along z-axis ejector. The two dimensional static pressure was lower than three dimensional simulation. It because the different boundary modeling condition which in two dimensional the pressure was lower. The difference happened in normal shock wave mixing flow. In two dimensional the static pressure was not dramatically increase, instead in three dimensional simulation it was dramatically increase in mixing chamber. It was because the different CO<sub>2</sub> flown direction where in two dimensional the flow was in the same direction with motive steam, instead in three dimensional the flow direction was perpendicular with motive steam flow which was suitable with the ejector geometry. In the two dimensional simulation shown that normal shock wave happened in diffuser part because of the different between surface areas.



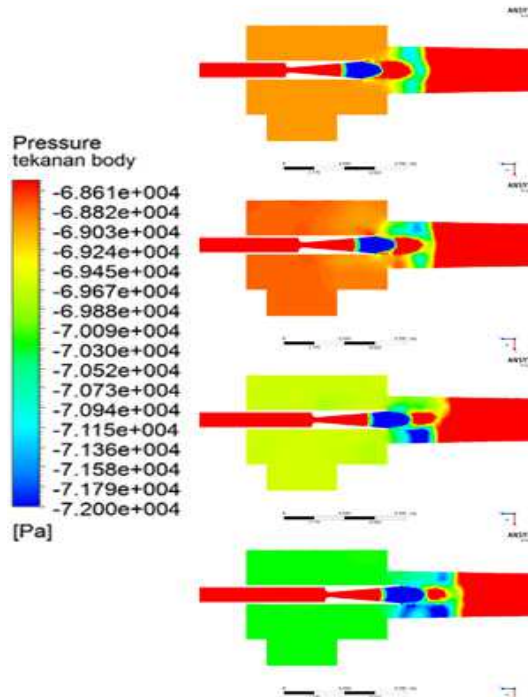
**Figure 7.** Static Pressure Distribution Graph along x-axis ejector

In certain position in mixing chamber, the water-vapor and CO<sub>2</sub> mixing have through normal shock wave, where the static pressure increased dramatically because of mixing flow velocity from supersonic to subsonic. The changes caused by reverse flow phenomenon in CO<sub>2</sub> flow which shown in Figure 8. The reverse flow of CO<sub>2</sub> prevent the mixing flow which made the velocity decreasing and also static pressure increasing at the same time at that part.



**Figure 8.** CO<sub>2</sub> streamline

**NXP VARIATION AGAINST VACUITY LEVEL**



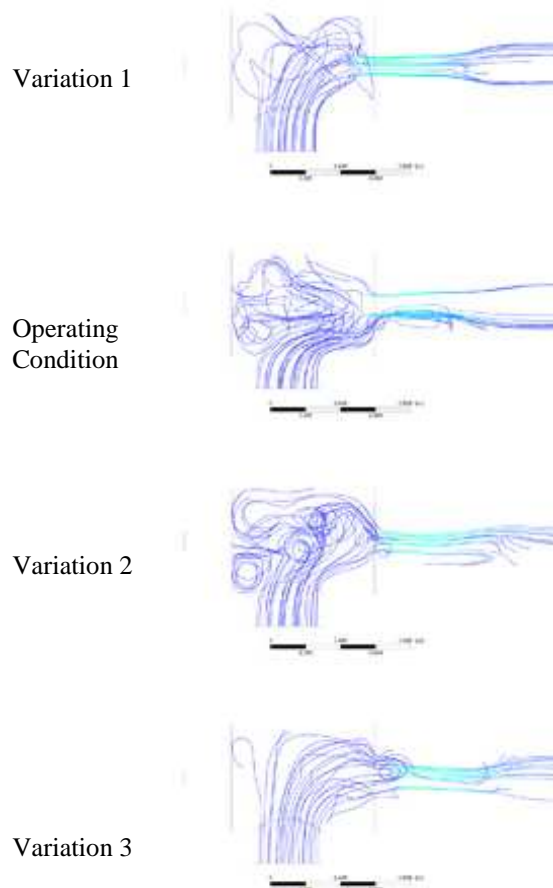
**Figure 9.** Vacuity pressure

The ejector vacuity depends on NXP which could increase the ejector performance (Safarudin, 2011). The changes of NXP were done by changing the extension of nozzle as shown in Figure9. The third variations had the lowest static pressure which the NXP placed inside the mixing chamber. Besides the actual NXP had the highest vacuity static pressure than the other. The increasing vacuity pressure happened in the ejector, so the ejector performance could increase by make the extension longer from the nozzle. The higher ejector vacuity pressure, the many NCG that inhaled. It

made the static pressure in condenser can be maintained. A 12" expansion used when the NCG in geothermal steam increased. The NCG streamline shown in Figure10, the third variations had smoother flow than the other in the actual condition. NCG directly extracted and came into the mixing chamber where the vacuity placed. For others, the maximum vacuity still in the body ejector, so the NCG was accumulated. Those made first vacuity variations, second, and actual condition had higher vacuity pressure.

**Table 6.** Vacuity Pressure around Nozzle Ejector

	Vacuity pressure (Pa)
Variation 1	-68938,738
Operating Condirion	-68743,367
Variation 2	-69631,469
Variation 3	-70234,234



**Figure 10.** NCG streamline

## 6. CONCLUSION

Convergence-divergence nozzle in the ejector used to increasing the motive steam flow velocity from subsonic to supersonic. Based on Venturi tube principle the static pressure in motive steam way would be smaller. The

different pressure in the area with suction ejector caused NCG in condenser expanded to the ejector. The NCG flow direction which perpendicular by the motive steam made the normal shock wave happened sooner in mixing chamber. In two dimensional simulation, the normal shock wave happened in diffuser ejector because of the different between throat and ejector surface area. But the physical phenomenon between two dimensional and three dimensional simulation which shown in the graph was same. NXP in mixing chamber caused the NCG directly go to the area. The area around the ejector could be more vacuity until the more extracted NCG came in. This NXP is suitable for use when NCG on geothermal steam increases. It can also be used to decrease the pressure in the condenser. The more NCG extracted in the condenser, the pressure in the condenser will decrease. Based on Rankine's cycle as shown in Figure 1, the decrease of pressure in condenser will cause the enthalpy from the outlet of turbine will decrease and it means more power can be generated by the turbine. So performance of the turbine can be increases and the total efficiency of geothermal power plants can also be increased as well.

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