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Comparison Between Variable and Fixed Geometry in Geothermal Power Plants

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POWER PLANTS

Power plant projects in general and renewable power plant projects in particular require numerous decisions and choices. Some of the most obvious questions for geothermal power plants are geographical region, site, plant type, financing and power purchase agreement. Some of the next tier decisions had to do with types of evaporators, condenser, turbines, generator, controls and control logics. There are several lower tier decisions that are not going to be discussed in this writing. The objective of this article is to highlight one important feature of turbine, variable inlet guide vanes, and present its utilization in an inflow radial turbine or turbo expander.

Types of Geothermal Power Plants:

Geothermal resource temperature varies from region to region and even amongst sites in the same region. Resource temperature determines type of geothermal power plant of Direct Steam (DS), Flash Steam, Organic Rankin Cycle (ORC) and Kalina Cycle (KC).

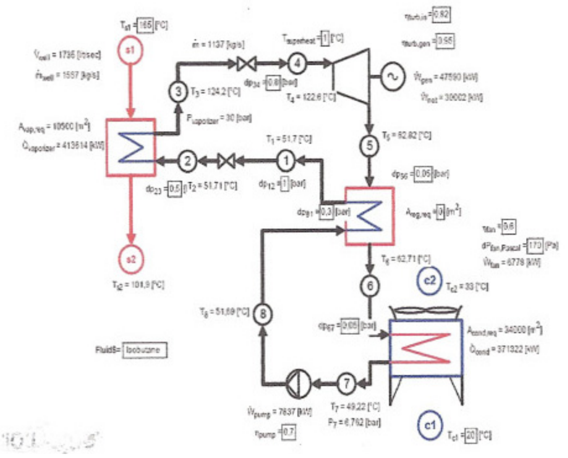

Figure 1: Process Flow Diagram

Figure [1] shows process flow diagram of a geothermal power plant. This schematic applies to ORC or KC geothermal plant. As shown, hot geothermal fluid evaporates an intermediate fluid to its saturation or slightly super heated conditions. The vapor enters a turbine where it expands and the turbine rotating wheel extracts energy to drive an electric generator. The turbine discharge stream flows to a condenser where it cools down and condenses into liquid. The intermediate fluid in liquid state is pumped back to the evaporator and the latter cycle is repeated. The turbine is the most critical equipment in this cycle. There are two types of turbines to be selected by the plant designer, axial or radial turbine. In an axial turbine high pressure fluid enters into the turbine wheel in an axial direction and discharge in an axial direction after expansion Figure 2a.

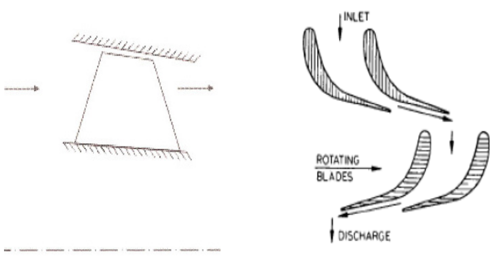

Figure 2a: Axial Turbine

In radial turbine high pressure fluid enters in a radial direction and exit in an axial direction after expansion figure 2

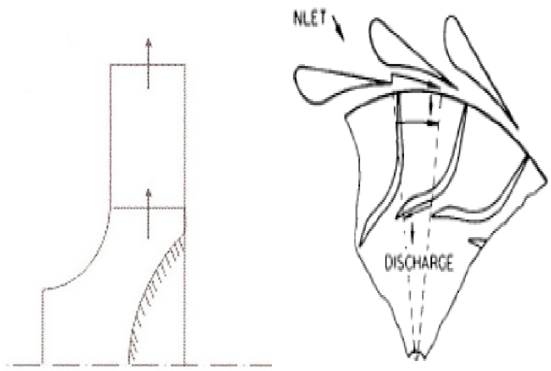

Figure 2b: Radial Turbine, Turbo Expander

Inflow Radial Turbine, Turbo Expander:

Turbo expander technology was developed and utilized in air separation industry in late 1930's. The technology has been developed considerably in the last seventy years. It has become one of the main and most essential turbomachine in natural gas processing, petrochemical, energy recovery and many other related industries in addition to air separation.

Inflow radial turbine design could accommodate variable inlet guide vanes. The variable inlet guide vanes function is to convert a portion of static head into kinetic energy and direct flow at an optimal direction into the turbo expander wheel. Expander wheel extracts energy from the fluid and produce mechanical energy that drives an electric generator coupled to the other end of rotor.

The above mentioned characteristic of the variable inlet guide vanes, guide flow in an optimal direction into the turbo expander wheel, is an important feature and the most differentiating advantage of a radial turbine over an axial turbine in geothermal energy recovery plants. Figure 3 depicts schematic of turbo expander variable inlet guide vanes and wheel.

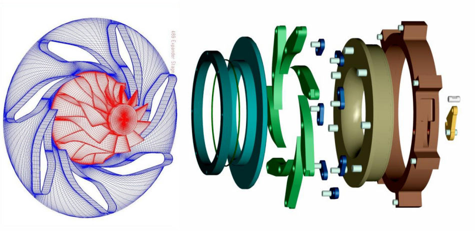

Figure 3: Variable Inlet Guide Vanes

Figure 4 portraits an inlet guide vane segment

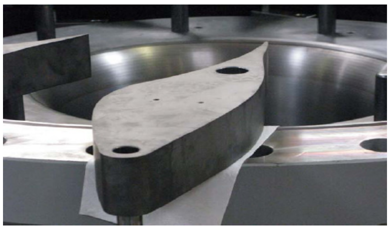

Figure 4: An Inlet Guide Vane Segment

Figure 5 shows variable inlet guide vanes assembly

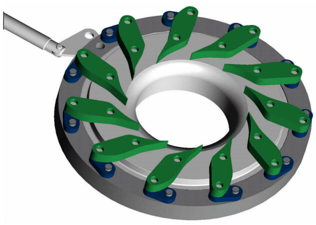

Figure 5: Variable Inlet Guide Vanes Assembly

A Typical Geothermal Power Plant with Organic Rankin Cycle:

To demonstrate the above concept we consider a hypothetical geothermal power plant. Figure 1 demonstrates Process Flow Diagram (PFD) for the plant. This plant utilizes commercial grade iso-butane as an intermediate fluid and air condensers.

Operation and performance of condenser is a function of the ambient temperature. Assuming the site is in state of Nevada in the United States of America, variation of annual ambient temperature is shown in Figure 6.

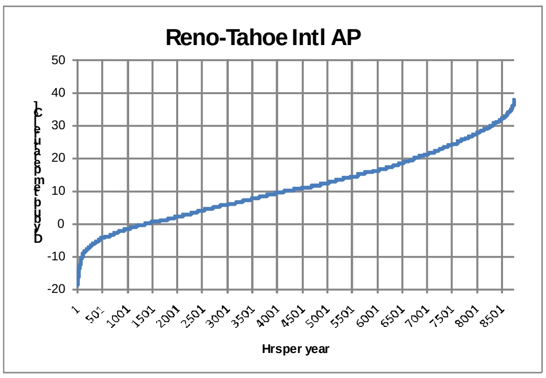

Figure 6: Typical Annual Ambient Temperature

The colder temperature in winter results in lower condenser pressure and hence there is more differential pressure across the turbo expander. The latter translates in more energy to be extracted by the expander and hence more electrical power on generator output terminal.

The condenser pressure increases in the hot days of summer and hence the plant out put is reduced due to lower differential pressure across the turbo expander.

Table 1 show the design, winter and summer performance of the turbo expander for the given environmental conditions.

Table 1 Turbo Expander Performance

Process Parameters	Units	Design	Summer	Winter
Fluid Molecular Weight	kg/kmol	58.08	58.08	58.08
Inlet Pressure	bara	35.50	35.50	35.50
Inlet Temperature	°c	145.50	145.50	145.50
Discharge Pressure	bara	4.58	8.00	2.75
Discharge Temperature	°c	69.25	87.90	63.42
Mass Flow	kg/hr	497,725	497,725	497,725
Discharge Volumetric Flow	nm3/hr	46,195	26,450	77,900
Efficiency	%	83	77	75
Generator Power Output	kw	9,700	6,150	10,500

As shown in Table 1 expander volumetric flows varies by + 69% in winter and – 43% in summer time. This variation in flow implies that the turbo expander variable inlet guide vanes have to be adjusted accordingly and these adjustments have to be consistent with variation of the turbo expander pressure ratios of 4.44 and 12.91 for summer and winter conditions respectively.

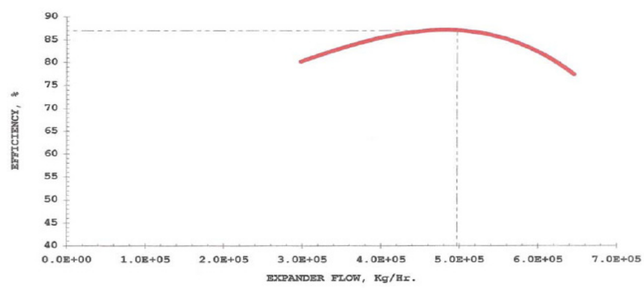

Figure 7: Turbo Expander Efficiency versus Flow

Figures 7 and Figure 8 depict turbo expander isentropic efficiency and power output variations with respect to the expander volumetric flow. As shown, efficiency reduction due to change in volumetric flow, or equivalently pressure ratio, is not too much and hence power recovery remains at high level and considerably more than those of an axial turbine. As a matter of fact an axial turbine cannot operate with high pressure ratio across the expander. Two stage axial turbines were required if this hypothetical plant were to be configured with axial turbines.

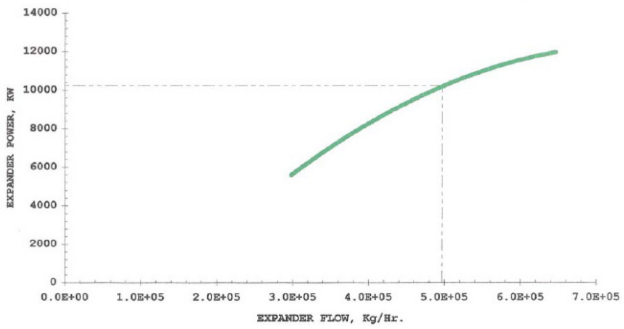

Figure 8: Turbo Expander Power versus Flow

Comparison of Radial and Axial Turbine Performance:

Tables 2 and 3 depict performance of a radial turbine with variable inlet guide vanes and an axial turbine with fixed inlet guide vanes with more details. As shown the expander with variable geometry performs with higher efficiency over the entire off design cases. The difference is less around the design point and as the off design point become moves further away from the design, performance of a fixed geometry expander deteriorate more. At 50% of the design load the difference between variable and fixed geometry expanders approaches to approximately 16 % in favor of the variable geometry expander.

Table 2. Performance of Variable Geometry Expander

DESIGN POINT	**VARIABLE GEOMETRY**				
100%	**90%**	**80%**	**70%**	**60%**	**50%**
100000	90000	80000	70000	60000	50000
10.0	10.0	10.0	10.0	10.0	10.0
31.0	**31.0**	**31.0**	**31.0**	**31.0**	**31.0**
124.4	**124.4**	**124.4**	**124.4**	**124.4**	**124.4**
685.8	685.8	685.8	685.8	685.8	685.8
2.384	2.384	2.384	2.384	2.384	2.384
613.9	613.9	613.9	613.9	613.9	613.9
4.50	4.5	4.5	4.5	4.5	4.5
34.00	34.0	34.0	34.0	34.0	34.0
34.1	34.10	34.10	34.10	34.10	34.10
282.8	282.8	282.8	282.8	282.8	282.8
248	**223**	**199**	**174**	**149**	**124**
893.3	804.0	714.6	625.3	536.0	446.7
100%	90.0%	80.0%	70.0%	60.0%	50.0%
87.0%	**86.0%**	**85.0%**	**83.5%**	**80.0%**	**75.0%**
15,536	13,822	12,143	10,438	8,572	6,697
3.0%					
466	466	466	466	466	466
3.0%					
452	452	452	452	452	452
14618	**12903**	**11225**	**9520**	**7653**	**5778**
	88.3%	**76.8%**	**65.1%**	**52.4%**	**39.5%**

Table 3. Performance of Variable Geometry Expander

DESIGN POINT	**FIXED GEOMETRY**				
100%	**90%**	**80%**	**70%**	**60%**	**50%**
100000	90000	80000	70000	60000	50000
10.0	10.0	10.0	10.0	10.0	10.0
31.0	**26.9**	**23.2**	**19.8**	**16.5**	**13.3**
124.4	**116**	**108**	**99**	**90**	**79**
	115.9	*107.5*	*98.8*	89.2	78.5
685.8	685.8	683.7	676.4	669.2	657.0
2.384	2.395	2.402	2.397	2.396	2.385
613.9	617.3	619.5	618.0	617.5	614.0
4.50	4.5	4.5	4.5	4.5	4.5
34.00	34.00	34.00	34.00	34.00	34.00
34.1	30.00	26.00	22.00	19.00	15.00
	29.62	25.53	21.77	18.12	14.60
282.8	282.6	282.4	282.2	282.1	281.9
248	**223**	**199**	**178**	**155**	**133**
893.3	803.5	717.7	639.3	558.0	479.8
100%	90.0%	80.3%	71.6%	62.5%	53.7%
87.0%	**86.0%**	**85.0%**	**83.5%**	**80.0%**	**75.0%**
15,536	13,165	10,880	8,659	6,404	4,302
3.0%					
466	466	466	466	466	466
3.0%					
452	452	452	452	452	452
14618	**12247**	**9962**	**7741**	**5486**	**3384**
	83.8%	**68.1%**	**53.0%**	**37.5%**	**23.1%**

Figure 9 is graphical representation of difference in performance of variable and fixed geometry expanders in terms of power output. The variable geometry expander produces more power consistently as an operating point moves further away from the design point.

Figure 10 shows expander process inlet pressure versus load. It is clear that the variable geometry expander is able to maintain a constant inlet pressure while the fixed geometry expander is incapable of doing so and hence deterioration of its performance.

CONCLUSIONS

Radial inflow turbo expander has become the prime choice for energy recovery in general and geothermal power plants utilizing Organic Rankin Cycle in particular. Radial turbo expanders could be designed with higher pressure ratios and maintain high efficiency over a wide range of flow variations

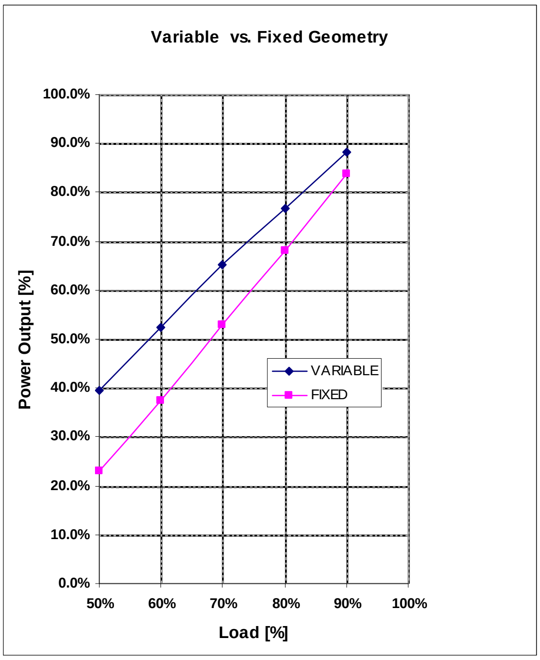

Figure 9: Power Output versus Percent Load

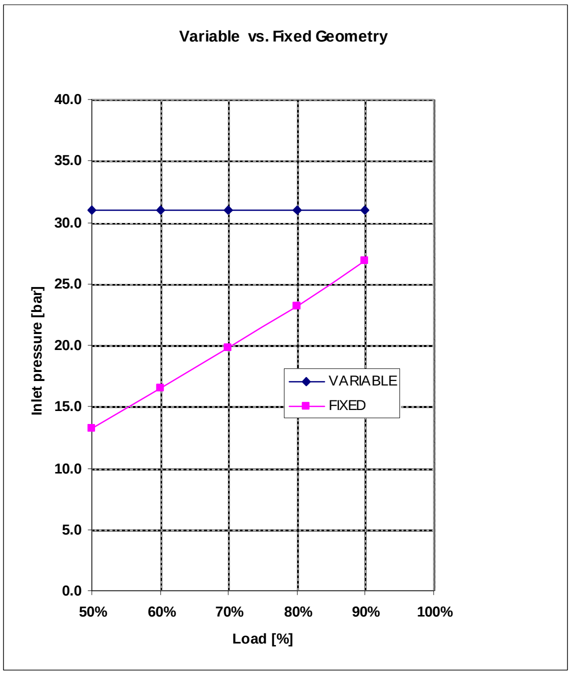

Figure 10: Expander Inlet Pressure versus Percent Load