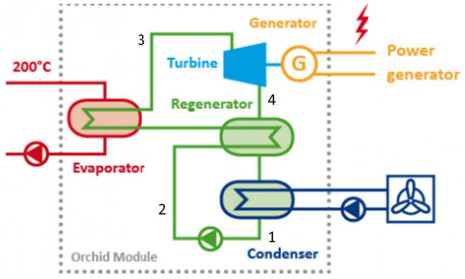
Design of Radial Turbo-Expanders for Small Organic Rankine Cycle System

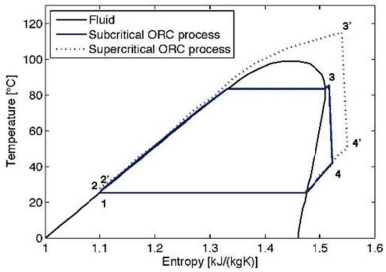
Ari Darmawan Pasek[1], **Maulana Arifin**[1] ,

[1]Faculty of Mechanical and Aerospace Engineering – Institute Technology Bandung
Jl. Ganesha No.10 Taman Sari, Bandung 41032 Jawa Barat
Telp. 022 2504243, Fax 022 2534099
E-mail: aripasek@gmail.com

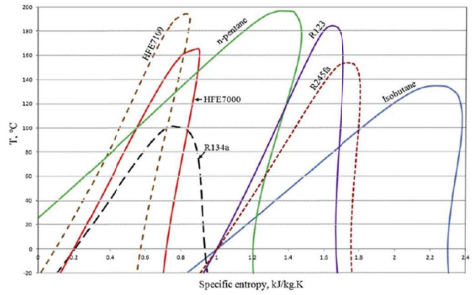
INDONESIA: Consist of many islands, many abundant heat resources such as solar and biomass, refrigeration unit for seafood, agriculture and poultry product in remote area need isolated/out-grid electric power generation, Organic Rankine Cycle could be powered by the solar or biomass heat to produce the electric power.

ORGANIC RANKINE CYCLE:





ORGANIC FLUID:



RADIAL TURBO EXPANDER:

- Simpler: One piece casting
- Compact
- Lighter
- Large specific power
- Higher efficiency

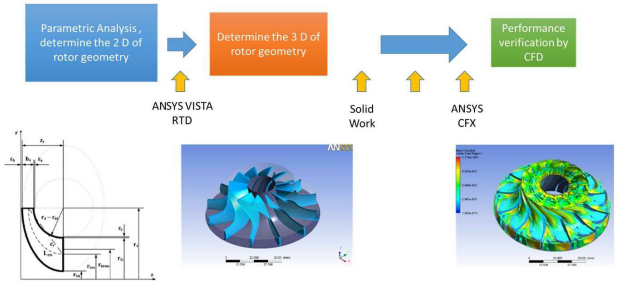
OBJECTIVE:

To determine radial turbo expander geometry for micro power generation

- Output power 5—10 kW
- Rotor diameter: around 250 mm
- Fluid inlet temperature: less than 200 °C
- Fluid inlet Pressure: less than 10 bara
- Fluid mass flow rate: less than 1 kg/s
- Rotor speed: 5,000—30,000 rpm

	R134a	R143a	R245fa	n-Pentane	R123
Formula	CH_2FCF_3	CF_3CH_3	$CF_3CH_2CHF_2$	C_5H_{12}	$CHCl_2CF_3$
Molecular mass	102	84	134	72	153
NBP, °C	-26.3	-47.09	15.3	36.0	27.8
T crit, °C	101.5	72.86	157.5	196.5	183.7
P crit, MPa	4,06	3,76	3,64	3,36	3,66
Latent Heat, at NBP, kJ/kg	155.4	231.0	177.1	349.0	168.4
ODP	0	0	0	0	0.02-0.06
GWP	1300	4300	1030	20	120
Flammability, Toxicity	A1	A2	B1	A3	A1

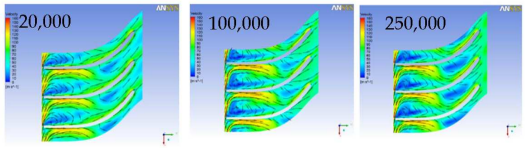
METHODOLOGY:



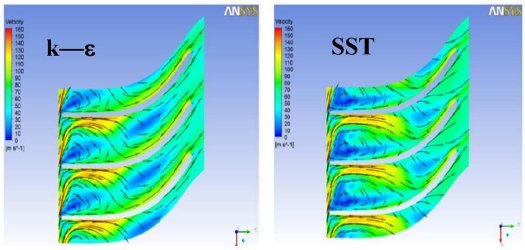
Input Parameter	Unit	R134a	R123	R245fa	R143a	n-Pentane
Mass Flow Rate ($\dot{m}$)	kg/s	0.40	0.40	0.40	0.40	0.40
Rotarional Speed (N)	rpm	15000	15000	15000	15000	15000
Inlet Total Temperature (Assumed $T_{01} = T_{04}$)	K	373	373	373	373	373
Total inlet Pressure (assumed $\Delta p_0=0$) $p_{04}=p_{01}-\Delta p_0$	bar	5	5	5	5	5
Loading Coefficient (ψ)	-	0.90	0.90	0.90	0.90	0.90
Flow Coefficient (φ)	-	0.30	0.30	0.30	0.30	0.30
Meridional Speed Ratio (ξ) C_{m4}/C_{m6}	-	1	1	1	1	1
Inlet rotor Radius Ratio (r_{6h}/r_4)	-	0.3	0.3	0.3	0.3	0.3

Result/ output parameter	Unit	R134a	R123	R245fa	R143a	n-Pentane
Absolute meridional velocity (C_{m4})(inlet)	m/s	50	44	43	48	49
Blade speed (U_4)	m/s	167	146	143	160	163
Absolute tangential velocity ($C_{\theta 4}$)	m/s	150	132	129	144	147
Absolute flow angle (inlet) (α_4)	Degree	71.57°	71.57°	71.57°	71.57°	71.57°
Relative flow angle (inlet) (β_4)	Degree	-18.43°	-18.43°	-18.43°	-18.43°	-18.43°
Absolute velocity (C_4)	m/s	158	139	136	151	155
Relative absolute inlet (W_4)	m/s	52.7	46.38	45.33	50.60	51.60
Inlet Temperature (T_4)	K	360.47	361.15	364.37	362.60	367.37
Inlet Pressure (P_4)	bar	3.60	3.75	3.93	3.85	4.15
Inlet Area (A_4)	m^2	$6.5x10^{-4}$	$4.7x10^{-4}$	$5.3x10^{-4}$	$7.7x10^{-4}$	$8.3x10^{-4}$
Radius rotor (r_4)	m	0.100	0.093	0.091	0.101	0.104
Inlet Blade height (b_4)	m	0.010	0.008	0.009	0.012	0.012
Inlet Density (ρ_4)	Kg/m^3	12.238	19.121	17.384	10.737	9.813
Inlet Mach number (M_4)	-	0.87	0.93	0.85	0.75	0.72

GRID NUMBER EFFECT:



TURBULENT MODEL EFFECT:



CONCLUSION:

The higher the number of grid will gives better and accurate results. Although time consuming grid number larger than 250,000 is recommended because it will gives different results which shows important phenomena. It is recommended to use SST models for turbulent model in the numerical analysis. Int this study this model gives higher power output. However this results has to be verify in the experimental study .R134a gives better performance compare to other for this particular conditions: mass flow rate 0.4 kg/s, 15,000 rpm, inlet pressure 5 bar, and inlet temperature 373K. At above stated condition, the expander with R134a produces 6,7 kW power output , with total efficiency-to-static (η_{ts}) 0,71. On the other hands R123 only produces 5.5 kW, with total efficiency-to-static (η_{ts}) 0,66. Using the method described in this paper, it is now easier to develop the 3D axial turbine geometry and their coordinates. These coordinate can be imported to a computer numerical control machine for fabrication.

ACKNOWLEDGEMENT:

Authors would like to express gratitude to New and Renewable Energy Research Centre, Institute Technology of Bandung for the research grant awarded to the author, and, all members of the Research Centre for Electrical Power and Mechatronics Indonesia Institute of Science for any assistances those have been given.