RECOVERY OF WASTE HEAT FROM THE COAL-FIRED POWER UNIT USING ORGANIC RANKINE CYCLE

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INTRODUCTION

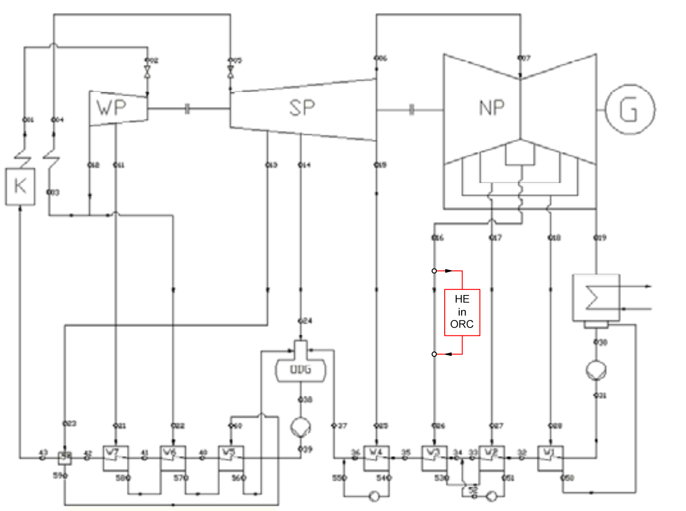
Application of ORC in the installation of heat recovery from the power unit is described. Presented works form a part of the national strategic project. The analysis of possible configurations of waste recovery is done in several stages. In the first stage it is assumed that the ORC evaporator is supplied with hot water of temperature equal to 80ºC. Such temperature of hot water is coming from the energy conversion of all identified and possible to use waste energy sources in the power plant. Next, attention is focused on the possibility of increasing the upper temperature of the cycle. That could be done, for example by incorporation of absorption heat pumps or solar collectors in the cycle. Another way is to consider utilisation of the bleed steam. Presented reference power plant allows utilisation of bleed steam from different parts of turbine. Another way to increase the efficiency of the ORC power plant is to reduce the condensation temperature. The way to achive that is to use the ground to aid heat transfer during the summer months and air-cooled condensers in winter. That leaves us with the maximum condensation temperature below 10ºC. The ground, however must be regenerated in the period of time not cooperating with the ORC unit and that procedure also requires to pump ambient air through the underground heat exchanger, contributing in such way to increase of energy consumption of the system.

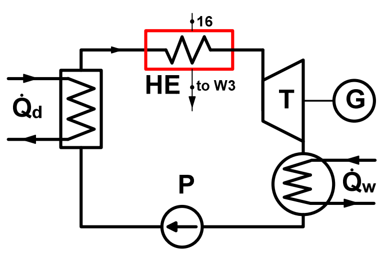
SELECTION OF REFERENCE PLANT PARAMETERS

Considered reference unit has following operation parameters:

1. Live and secondary steam at the boiler outlet:
   - live steam parameters: p_0 = 30.3 MPa and T_0 = 653 °C,
   - temperature of secondary steam: T_w = 672 °C,
2. Live and secondary steam at the turbine inlet:
   - live steam parameters: p_0 = 30 MPa and T_0 = 650 °C,
   - temperature of secondary steam: T_w = 670 °C,
3. Pressure of secondary superheated steam:
   initally assumed value of p_{wt} = (0,19-0,21) p_0 = 6 MPa (final value resulting from optimised cycle)
4. Unit electrical power:
   initially assumed at the level of approx. 900MW,
   mass flow rate of live steam m_0 = 2 200 t/h,
   final value dependent upon balance calculations
5. Feedwater temperature
   Value initially assumed as: T_{wz} = 310 °C (final value after unit optimisation)
6. Boiler efficiency:
   Hard coal: 94,5%, at exhaust gas temperature: 115(120) °C,
   Lignite: 90% , at exhaust gas temperature: 170°C.

CONSIDERED INSTALLATION FOR ORC APPLICATION





REFERENCE CASE

No	Fluid	m	Qd	Qw	N_p	N_t	η ORC	η b	N_t-Np
		kg/s	kW	kW	kW	kW	-	-	kW
1	**MDM siloxane**	3,851	1000	905,7	0,03	94,3	0,094	0,820	94,26
2	**D5 siloxane**	4,770	1000	905,2	0,00	94,8	0,095	0,825	94,77
3	**R236fa**	6,106	1000	904,2	3,76	99,5	0,096	0,834	95,76
4	**MM siloxane**	3,503	1000	904,1	0,19	96,1	0,096	0,834	95,87
5	**D4 siloxan**	4,331	1000	903,9	0,02	96,1	0,096	0,837	96,12
6	**R236ea**	5,649	1000	902,1	2,71	100,6	0,098	0,852	97,90
7	**Izobutan**	2,729	1000	901,0	4,21	103,2	0,099	0,862	98,99
8	**R245fa**	4,713	1000	900,3	1,93	101,6	0,100	0,868	99,67
9	**R365mfc**	4,399	1000	900,0	0,88	100,8	0,100	0,870	99,92
10	**Butan**	2,469	1000	900,0	2,83	102,9	0,100	0,871	100,08
11	**Izopentan**	2,503	1000	899,5	1,27	101,8	0,101	0,875	100,53
12	**Izoheksan**	2,456	1000	899,2	0,50	101,3	0,101	0,878	100,80
13	**R245ca**	4,413	1000	898,8	1,27	102,5	0,101	0,881	101,23
14	**Pentan**	2,372	1000	899,0	0,98	102,0	0,101	0,879	101,02
15	**Heksan**	2,350	1000	899,2	0,37	101,2	0,101	0,877	100,83
16	**Heptan**	2,339	1000	898,5	0,15	101,6	0,102	0,883	101,45
17	**Amoniak**	0,902	1000	895,1	4,02	108,9	0,105	0,913	104,88
18	**Etanol**	1,028	1000	891,7	0,11	108,5	0,108	0,943	108,39
19	**Metanol**	0,841	1000	890,2	0,15	109,9	0,110	0,956	109,75

ORC calculations at boiling/condensation parameters 75/35°C, η_T=100%, η_P=90% , η_C=11,5% , Q_d = 1MW

INCREASE OF UPPER SOURCE TEMPERATURE

Fluid	T_1	P_1	h_1	h_{2s}	T_2	h_3	h_4	h_5	h_6	T_6	η_{th} (η_T=1.0) no regen	η_{th} (η_T=1.0) with regen
	ºC	bar	kJ/kg	kJ/kg	ºC	kJ/kg	kJ/kg	kJ/kg	kJ/kg	ºC	-	-
Dodecane	120	0,049	43,878	-73,38	55,973	-155,15	-525,43	-525,43	-443,66	46,76	0,206	0,241
D4	120	0,188	54,06	5,91	82,81	-57,33	-242,59	-242,58	-179,34	70,90	0,162	0,206
Decane	120	0,202	163,02	40,95	55,45	-35,06	-404,53	-404,49	-328,48	44,54	0,215	0,248
Nonane	120	0,415	226,03	103,74	54,73	28,86	-342,37	-342,31	-267,43	43,81	0,215	0,248
Toluene	120	1,314	373,46	241,80	13,21	238,34	-183,41	-183,26	-179,80	12,11	0,236	0,238
MDM	120	0,396	99,30	29,17	74,92	-64,51	-276,16	-276,11	-182,43	60,92	0,187	0,249
ethanol	120	4,283	1322,8	1053,10	10,00	1159,00	223,29	223,82	223,82	10,06	0,245	0,245
Woda	120	1,987	2705,9	2017,80	10,00	2519,20	42,02	42,22	42,22	10,00	0,258	0,258
R600a	120	28,366	686,46	588,44	22,12	567,78	223,15	227,73	248,39	19,94	0,204	0,224
R245fa	120	19,275	484,39	426,46	26,24	411,79	212,84	214,18	228,85	21,85	0,209	0,227
R245ca	120	14,351	504,76	441,95	32,30	421,82	212,89	213,86	233,99	25,68	0,213	0,232
C_5F_{12}	120	11,922	158,80	128,02	70,53	76,82	-21,23	-20,54	30,66	57,19	0,168	0,240

Comparison of thermodynamical characteristics of potential working fluids, (T_H=120ºC, T_L=10ºC,η_C=0.280).

INCREASE OF LOWER SOURCE TEMPERATURE

No	Fluid	ORC 75/35 for Qd = 1MW			ORC 115/35 for Qd = 590kW		
		N_t	η ORC	η b	N_t	η ORC	η b
		kW	-	-	kW	-	-
1	**MDM siloxane**	94,3	0,094	0,820	85,2	0,144	0,700
2	**D5 siloxane**	94,8	0,095	0,825	85,6	0,145	0,704
3	**R236fa**	99,5	0,096	0,834	92,5	0,146	0,708
4	**MM siloxane**	96,1	0,096	0,834	88,1	0,149	0,722
5	**D4 siloxan**	96,1	0,096	0,837	88,2	0,150	0,725
6	**R236ea**	100,6	0,098	0,852	94,3	0,152	0,739
7	**Izobutan**	103,2	0,099	0,862	97,4	0,154	0,747
8	**R245fa**	101,6	0,100	0,868	97,1	0,159	0,772
9	**R365mfc**	100,8	0,100	0,870	95,5	0,159	0,773
10	**Butan**	102,9	0,100	0,871	98,6	0,160	0,775
11	**Izopentan**	101,8	0,101	0,875	97,1	0,161	0,782
12	**Izoheksan**	101,3	0,101	0,878	95,9	0,161	0,782
13	**R245ca**	102,5	0,101	0,881	97,8	0,162	0,787
14	**Pentan**	102,0	0,101	0,879	97,5	0,163	0,789
15	**Heksan**	101,2	0,101	0,877	96,6	0,163	0,789
16	**Heptan**	101,6	0,102	0,883	96,8	0,164	0,794
17	**Amoniak**	108,9	0,105	0,913	106,6	0,167	0,812
18	**Etanol**	108,5	0,108	0,943	108,8	0,184	0,892
19	**Metanol**	109,9	0,110	0,956	111,6	0,188	0,914

ORC calculations at boiling/condensation parameters 75/35°C, η_T=100%, η_P=90% , η_C=11,5%, heat input Q_d = 1MW and 115/35°C, η_T=100%, η_P=90% , η_C=20,6%, heat input Q_d = 0.59MW

CONCLUSIONS

The concept of development of heat recovery from the power unit using the ORC technology seems to be attractive. There are no similar approaches elsewhere in the world. The experiences from the present project will be beneficial to other uses. The major problem is rather low temperature of the upper source which results in small values of thermal efficiency of cycles. Innovative solutions in the considered case would require selection of the appropriate working fluid. That fluid must obey most of the requirements defined for such working fluids. The system should preferably be without the regenerative heat exchanger, as it increases the cost of installation. In the paper several of such fluids have been considered. It results from the presented analysis that the best fluids are belonging to the group of wet fluids such as ethanol and methanol or the dry group where mentioned should be silicon oils D4, MDM and toluene.

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