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Thermodynamic Systems for Industrial Waste Heat Recovery and New Trends of Refrigerants

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Abstract—*Approximately 20-50% of total energy input is dumped into atmosphere from different industrial process of manufacturing and power industry, this industrial waste heat (IWH) may reuse for clean power generation. Numerous technologies have been proposed for waste heat recovery (WHR) like Tri-Generation (combined power, heating and refrigeration effect) system which is also known as cogeneration cycle based on organic Rankine cycle (ORC) systems where refrigerants are used as a working fluid as well as co-generation systems with solar integrated system also. This paper focuses on waste heat recovery (WHR) systems and simultaneous generation of power, heating and cooling as output through reprocess of waste energy from cement, glass and steel industrial sectors with utilization of new trends of refrigerants which have low value of global warming potential (GWP) and ozone depletion potential (ODP). The key benefits of waste heat recovery technologies are low energy consumption, less carbon-emission, low operating cost and the employment of renewable energy systems.*

1. INTRODUCTION

Nowadays due to predicted increase in energy consumption of the world, more environmental concerns and less dependency on fossil fuels, demand for sophisticated power supply options is greatly increased. Environmental concerns will be in form of global warming, acid rains, air, water and soil pollution, ozone depletion, forest devastation and radioactive substances emissions. Utilizing waste heats along with attempts to derive energy out of renewable resources as low grade thermal heat sources have motivated the use of advanced energy recovery systems. The present research issue provides new concept and development of low Global Warming Potential (GWP) and *Ozone Depletion Potential* (ODP) Refrigerants based utilities for an industrial application. The simulated performance is discussed and relate to improving future modeling and system design efforts. There is lots of processes can be developed where we can use WHR by using organic fluid or refrigerants. We can generate power (Combined cycle / Binary cycle), we can generate cooling effect by trigeneration process. Tri-generation technology is a technology that can provide simultaneously three forms of output energy; electrical power, heating and cooling. Trigeneration is also known as CCHP (Combined Cooling, Heating and Power) or CHRP (Combined Heating, Refrigeration and Power). In essence, trigeneration systems are CHP (Combined Heat and Power) or co-generation systems, integrated with a thermally driven refrigeration system to provide cooling as well as electrical power and heating.

2. WASTE HEAT RECOVERY SYSTEM (WHRS)

Energy recovery (High-Low grade) technology Review [12]

Three categories of wastage heat sources are distinguished with respect to the temperature level, low (<230^{0}C), medium (230-650 ^{0}C) and high (>650^{0}C).Waste heat sites and thermal levels are listed in table of energy recovery and its sources.

Table 1. Energy recovery and its sources

Heat Categories	Heat Sources	Temperature in 0C	Suggested recovery technology
High Grade (>6500C)	Solid waste	650-1000	Air preheating
	Nickel refining furnace	1370-1650	Steam generation for heating
	Copper reverberatory furnace	760-815	Thermoelectric and thermal PV
	Glass melting furnace	1000-1550	Heat exchanger for preheating
	Hydrogen plant	650-1000	Thermal PV
Medium Grade (230-6500C)	Steam boiler exhaust	230-480	Steam rankine cycle
	Gas turbine exhaust	370-540	Organic rankine cycle
	Drying and baking ovens	230-600	Thermal PV
	Catalytic crackers	425-650	Thermal PV
	Reciprocating engine exhaust	315-600	Thermoelectric
Low Grade (>2300C)	Welding and injection molding	32-88	Kalina cycle
	Hot processed liquids and solids	32-233	Organic rankine cycle

	Drying, Baking and Curing ovens	93-230	Absorption and adsorption cooling
	Bearing	32-88	Piezoelectric

2.1. High Grade Energy

The category of waste heat which temperature is more than 650^0 c. Which can be easily used in same industry such as Steel plants, Glass plants and Cement industries etc?

Status of Energy recovery technology in India [12]
Cement Industry

According to a study done by TURBODEN (one of the market leaders in ORC technology), a 2,500 ton per day plant of cement can be used to set up a 1.6 MW. waste heat recovery plant using the Organic Rankine Cycle. Based on this assumption and projected manufacturing capacity of cement industry in India, a rough potential of the electricity production from waste heat by ORC technology is estimated to be 574 MW.

Glass Industry

Typically, a 500 ton per day glass manufacturing plant will have potential for a 1 MW Organic Rankine Cycle waste heat recovery plant. The projected waste heat recovery potential through ORC in the glass industry in India is total potential estimated at around 36 MW by 2017.

Iron and Steel Industry

Typically, a 6,000 ton per day steel rolling mill has a potential of generating 2.4 MW of electricity through an Organic Rankine Cycle waste heat recovery plant. The projected waste heat recovery potential through ORC in the Iron and Steel sector is total potential estimated to be around 148.4 MW by 2017.

But this high grade energy is available very less in whole world so we cannot generate that much energy which can be helpful to the general people. So our main task is use WHR of the nonconventional energy.

ORC Status in India.

Table 2: ORC Development in India [12]

Sector	Capacity (MW)
1. Wastage Heat Recovery In Major Industry	
a) Cement	574.2
b) Glass	35.7
c) c. Iron and steel	148.4
Total	758.3
2.Renewable Energy	
a) Solar thermal energy storage	1440
b) Biogas plant	2208
c) Geothermal	NA
Total	3648
Grand Total	4406.3

2.2. Low Grade Energy

Renewable energy sources, such as solar thermal and geothermal, biomass, municipal solid waste (MSW) and vast amounts of industrial waste heat are potentially promising energy sources capable, in part, to meet the world electricity demand. However, the low grade heat from these sources cannot be converted efficiently to electrical power by using the conventional power generation methods. In this context, research on how to convert these low-grade temperature heat sources into electrical power is of great significance. However, the thermal efficiency of the conventional steam power generation considerably low and becomes uneconomically when steam temperature drops below 370 ˚C. It means that using water as a working fluid in Rankine cycle is more suitable for high temperature applications and large centralized systems. The organic Rankine cycle (ORC), whose most important feature is the possibility of using different low temperature heat sources for small and medium power generation, has been studied by many authors. In ORC's the problems encountered with water can be partially mitigated by selecting a suitable organic fluid, characterized by higher molecular mass and lower critical temperature than water. In the other words, the organic Rankine cycle (ORC) is a non-superheating thermodynamic cycle utilizing an organic working fluid to rotate an expander. The ORC systems employed a wide range of heat source, including solar energy, geothermal energy, biomass energy, industrial waste heat, fuel cell, and ocean energy etc. In addition, ORCs can be easily combined with other thermodynamic cycles, such as the internal combustion engine (ICE), thermoelectric generator, seawater desalination system, and Brayton cycle. Moreover, it also can be used as in a combined heat and power (CHP) and combined cooling and power system (CCHP). In the present work the influences of the working fluids' types and thermal physical properties on organic Rankine cycle performance are discussed; then, the comparison of the pure and mixed working fluids are presented. Present Literature review focus on ORC based wastage energy recovery systems, working fluid and their selection criteria with fluid properties, and technological development.

3. TRIGENERATION

Tri-generation is the simultaneous production of three forms of energy: electricity, heating and cooling. A trigeneration system can provide power, hot water, space heating and air conditioning from a single system. Generators lose heat as they create electricity. A tri-generation facility captures this heat that would otherwise be lost and uses it to generate both hot and cold water.

The chilled water is created by an absorption chiller, which is generated by the excess heat and this operates like a refrigerator. It creates water at sufficiently low temperatures to be used for air conditioning. [11]

3.1. Deployment of Trigeneration Units

As it was mentioned above, the trigeneration is the simultaneous production of three forms of energy. Typically, cooling, heating and power (CHP), from only one fuel input. Put another way, trigeneration power plants produce three different types of energy for the price of one. In general, the trigeneration energy systems reach overall system efficiencies of 86 % to 93 %. Typical "central" power plants, that do not need the heat generated from the combustion and power generation process, are only about 33 % efficient.

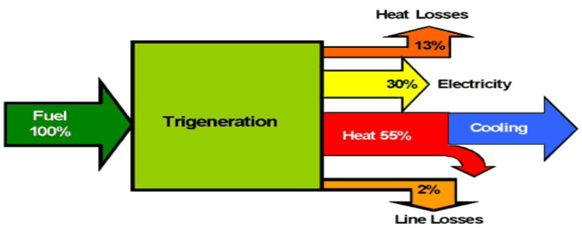

Figure 1: Trigeneration Diagram and Description [8]

(The trigeneration power plants have the high system efficiencies and are about 300 % more efficient than typical central power plants)

Trigeneration plants are mostly installed at locations that can benefit from all three forms of energy. These types of installations that install trigeneration energy systems are called "onsite power generation" and are also referred to as "decentralized energy." The advantages of Trigeneration system over conventional generation system using of LPG were confirmed after of number of trials of current Micro-Trigeneration system according to [6] as below:

1. Increased reliability and security of energy supply. Lower energy cost: the 75 % saving of operation cost compared to conventional unit.
2. Higher overall efficiency: 24 % higher than conventional unit.
3. Fuel energy losses reduced to approximately 4 % as against around 28 % in case of conventional system.
4. Recovered waste heat provides "free fuel" for heating water. 60 % of fuel input which otherwise would have lost to ambient in form of exhaust gas is used for water heating.
5. Clean energy supply with reduced Emission with LPG as fuel.

4. LITERATURE REVIEW

Chen and Goswami [3] proposed novel thermodynamic cycle that uses binary mixture to produce power and refrigeration simultaneously in one loop. This cycle is a combination of Rankine power and absorption cooling cycle. Its advantages include the production of power and cooling in the same cycle, the design flexibility to produce any combination of power and refrigeration, the efficient conversion of moderate temperature heat source and the possibility of improved resource utilization compared to separate power and cooling system. The binary mixture first used was ammonia-water and later on new binary fluids were proposed and studied**.**

Lu and Goswami [10] conducted a theoretical analysis for a combined power and refrigeration cycle. Proposed a combined power and refrigeration cycle which utilizes low temperature heat sources, such as geothermal energy, solar energy using flat plate collectors to produce power and refrigeration in the same cycle and showed the feasibility of the vapor generation and absorption condensation processes experimentally.

Vijayaraghavan and Goswami [13] investigated a combined power and cooling technology. For maximum resource utilization efficiency, the cycle configuration has been optimized. Similar to Kalina cycle, a thermal distillation scheme has been implemented.

Energetic performance comparison of three trigeneration systems is presented by Sulaiman et.al [1]. These trigeneration systems are SOFC–trigeneration, biomass-trigeneration and solar-trigeneration systems and this study showed that SOFC trigeneration cycle has maximum electric efficiency with respect to other cycle. Maximum trigeneration efficiency of SOFC trigeneration is 76% and biomass trigeneration is 90% as well as solar trigeneration is about 90% for the solar mode and 45% for storage mode.

Priyank et. al [2] study was focused on trigeneration cycle which is based on principal of cogeneration proposal towards vapor absorption cogeneration cycle. Matlab simulations were done on condenser as heat rejection, heat addition by reheater and for other components.

Goswami et. al [4] compares organic rankine cycle and supercritical rankine cycle on the basis of working fluid. There was study of working fluid and found that properties of working fluid take part in vital role in the cycle for that 35 fluid had screened out and plotted T-S diagram based on properties.

Carcasci et. al [5] studied of an organic rankine cycle in an intercooled gas turbine. There was four type of working fluid used in ORC. These working fluids were toluene, benzene, cyclopentane and cyclohexane and based on this working fluid thermal analysis was to be done.

Maidment et. al [7] studied on UK's supermarket on the basis of reduced energy used. The application of an integrated combined heat and power in the supermarket on the basis of subject of this paper. Paper describes combined heating, cooling and power requirement of a supermarket.

Thermal analysis was studied on combined rankine and refrigeration cycle for efficient use of low grade heat source. Working fluid used for this co generative cycle is ammonia water mixture. specific cooling capacity, total utilization work, and thermal efficiency has an optimum value with respect to the turbine inlet pressure [9].

5. WORKING FLUID

There are different sets of experiment done by the different scientist or scholars and they find the property of the working fluid by which these refrigerant will be categories

Table 3: Commercialized Working fluids [14]

S.No	Chemicals	Physical Data				Safety Data	Environmental Data		
		Molecular Mass (Kg/K mol)	Normal Boiling Point Temp (Tbp) in 0C	Critical Temp (Tcriti) in 0C	Critical Pressure (Pcriti) in MPa	ASHRAE Group	Atmospheric Life Time (ALT) in years	Ozone Depletion potential (ODP)	Global Warming Potential (GWP) of 100 years
1	RC118	200.03	-6.0	115.2	2.778	A1	3200	0	10225
2	R600a	58.12	-11.7	135	3.647	A3	0.017	0	~~20
3	R114	170.92	3.6	145.7	3.289	A1	300	1.00	10040
4	R600	58.12	-0.5	152	3.796	A3	0.018	0	~~20
5	R601	72.15	36.1	196.5	3.364	NA	0.01	0	~~20
6	R113	187.38	47.6	214.1	3.439	A1	85	1.000	6130
7	Cyclohexane	84.16	80.7	280.5	4.075	A3	NA	NA	NA
8	R290	44.10	-42.1	96.68	4.247	A3	0.041	0	~20
9	R407C	86.20	-43.6	86.79	4.597	A1	NA	0	1800
10	R32	52.02	-51.7	78.11	5.784	A2	4.9	0	675
11	R500	99.30	-33.0	105.5	4.455	A1	NA	0.738	8100
12	R152a	66.05	-24.0	113.3	4.520	A2	1.40	0	124
13	R717 (Ammonia)	17.03	-33.3	132.3	11.333	B2	0.1	0	<1
14	Ethanol	46.07	78.4	240.8	6.148	NA	NA	NA	NA
15	Methanol	32.04	64.4	240.2	8.104	NA	NA	NA	NA
16	R718 (Water)	10.2	100	374	22.064	A1	NA	0	<1
17	R134a	102.03	-26.1	101	4.059	A1	14.0	0	1430
18	R12	120.91	-29.8	112	4.114	A1	100	1.000	10890
19	R123	152.93	27.8	183.7	3.668	B1	1.3	0.02	77
20	R141b	116.95	32.0	204.2	4.249	NA	9.3	0.120	725
21	R245fa	134.05	15.3	154.1	3.64	B1	8.8	0	820
22	R236fa	152.0	-1.5	124.0	3.20	-	209	0	6300
23	R227ea	170.0	-17.5	102.0	2.95	-	36.5	0	2900
24	R1234yf	114.02	-29.45	94.7	3.382	A1	NA	~0	4

6. CONCLUSION

In general conventional steam cycle operates in medium to high temperatures and can not be cost effective at smaller scale or low temperature resources. In the low medium temperature range Organic Rankine, Kalina, Goswami, and Transcritical cycles have demonstrated. It is evident that an integrated approach towards operational efficiency improvements of existing systems, reduction of losses in operational mechanisms, end-use efficiency and also making use of waste heat recovery technologies are very much essential for energy conservation. The organic Rankine cycle applications in waste heat recovery. Working fluid properties and selection (including pure fluids and mixtures) was reviewed. Also some important physical properties of the working fluids for ORC and the performance of the system were introduced. Different applications of ORC systems including solar thermal, biomass ORC, solar thermal reverse osmosis desalination, geothermal application, and waste heat recover from industrial process were intensively investigated. The paper also presented the different employed expander in the ORC system and introduced many factors which should be considered such as the power capacity, isentropic efficiency, cost and complexity their application range. Environmental concern over climate change as well as energy price is reasons supporting application of the waste heat recover by the ORC technology. Reasonable focus has been paid on analysis and understanding of various aspects related to effectiveness of energy use. Still, in each area, potential exists for sizable research work.

REFERENCES

[1] Al-Sulaiman, F.A. Hamdullahpur F, Dincer I. Performance comparison of three trigeneration systems using organic rankine cycles. Energy 2011; 36:5741–54.

[2] Agrawal priyank. Thermodynamic Modeling of a Vapor Absorption Cogeneration Cycle. July 2013; ISSN 2278 – 9472.

[3] Chen H, Goswami DY, Stefanakos EK. A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renewable and Sustainable Energy Reviews 2010; 14:3059–67.

[4] Chen H, Goswami DY, Stefanakos EK. A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renew Sustain Energy Rev 2010; 14:3059–67.

[5] Carlo Carcascia, Lorenzo Winchlera. Thermodynamic analysis of an Organic Rankine Cycle for waste heat recovery from an aero derivative intercooled gas turbine. Energy Procedia 101 (2016) 862 – 869.

[6] Easow, R. Muley. Micro-Trigeneration: The best way for decentralized power, cooling and heating. 2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), pp. 459–466, ISBN 978-1-4244-6076-2, DOI: 10.1109/CITRES.2010.5619812.

[7] G.G. Maidment, R.M. Tozer, Combined cooling heat and power in supermarkets, Applied Thermal Engineering22 (2002) 653–665.

[8] Institute for Sustainable Futures, University of Technology, Sydney: Tri-generation. How does it work?

[9] Kyoung Hoon Kim, Giman Kim, and Chul Ho Han. Performance Assessment of Ammonia-Water Based Power and Refrigeration Cogeneration Cycle. International Journal of Materials, Mechanics and Manufacturing, Vol. 1, No. 1, February 2013.

[10] Lu. S., and Goswami, D.Y., (2003). Optimization of a novel combined power/refrigeration thermodynamic cycle, Journal of Solar Energy Engineering, Vol.125, No.2, pp.125-213.

[11] Renewable Energy Institute: Trigeneration Technologies Available (June 2011).

[12] Study of Industrial wastage heat recovery by turbdone, project of Govt. of India.

[13] Vijayaraghavan, S., and Goswami, D.Y., (2006). A combined power and cooling cycle modified to improve resource utilization efficiency using distillation stage, *Energy*, Vol.31, No.8, pp.1177-1196.

[14] V. Maizza, A. Maizza, Working fluids in non-steady flows for waste energy recovery systems, Applied Thermal Energy 16 (1996) 579-590.