INDUSTRIAL AND POWER PLANT WASTE HEAT RECOVERY SYSTEMS FOR COMBINED COOLING-HEATING AND POWER GENERATION

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Abstract-

Energy Intensive industries like, cement, steel, glass and metal, etcare responsible for environment's severe impact and high energy prices. Approximately 20-50% of total energy input is dumped into atmosphere from different industrial process, and 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, organic rankine cycle (ORC) based systems, co-generation systems with solar integrated also. This paper focuses on combined heating-cooling and power generation by WHR systems with role of new trends of refrigerants.The key benefits of WHRtechnologies are reduce environment impact, generation of process heating, power and cooling effect with low operating cost and the employment of renewable energy systems for heat recovery in energy efficient manner for conventional power plants and industries like steel,cementetc.The waste heat recovery from industries and power plant have tremendous potential for re-powering of plant and new market opportunities for employment of efficient heat recovery technology in terms of energy conservation and environment aspect.

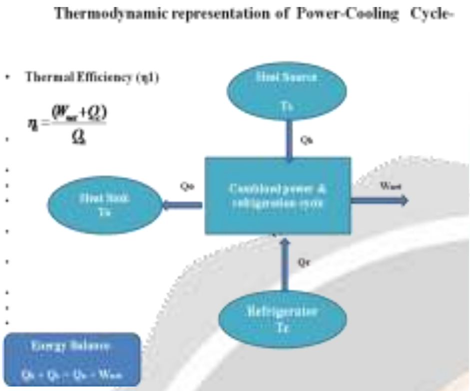
Keywords- Tri-Generation, ORC, GWP, ODP, Solar Energy,HRSG,CCHP

I. INTRODUCTION

Nowadays due to 40% predicted increase in energy consumption of the world, more environmental concerns form of global warming, acid rains, air, water and soil pollution, ozone depletion, forest devastation and radioactive substances emissions. Utilizing waste heat 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 the concept and employment of low global warming potential (GWP) and ozone depletion potential (ODP)values type chemicals (refrigerants) based utilities for IWH recovery application.

II. WASTE HEAT RECOVERY THERMAL SYSTEMS

A. **COMBINED AND COGENERATION SYSTEM (HEATING-POWER GENERATION CONCEPT)-**Cogeneration or combined heat and power (CHP) is use to generate electricity and useful heat or process heat at the same time through coupling of two different power cycles like gas turbine and steam turbine systems. In power generation,the production of electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put to use. Bazques and Strom And Maidment and Tozer have reviewed a number of combined energy production plants operating in supermarkets. TheyAnalyzed different schemes of combined energy production including different cooling and engine technologies [1-2]. BEE [4] summarized the popularity of topping and bottoming cycle concept of co-generation system which are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants. The waste gases coming out of the furnace is utilized in a boiler to generate steam, which drives the turbine to produce electricity.[4,55]



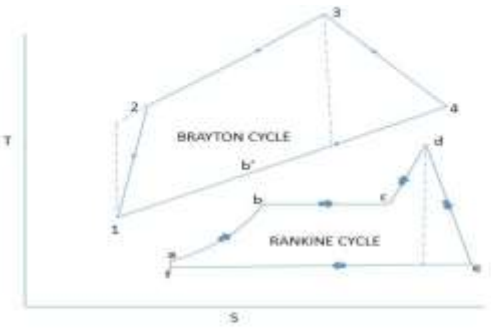
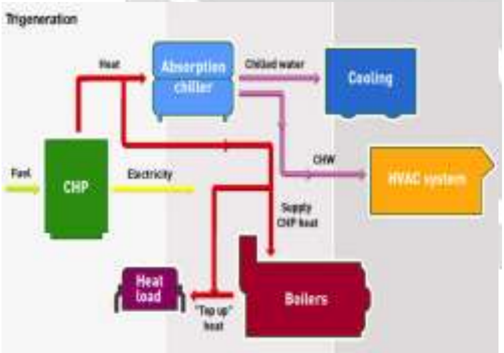


Fig-1: Thermodynamic concept of power-cooling system **Fig-2: Combined Power Cycle [55]**

B. TRIGENERATION SYSTEM -Tri-generation technology 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. Trigeneration systems can have overall efficiencies as high as 90% compared to 33%-35% for electricity generated in central power plants. [4,59]



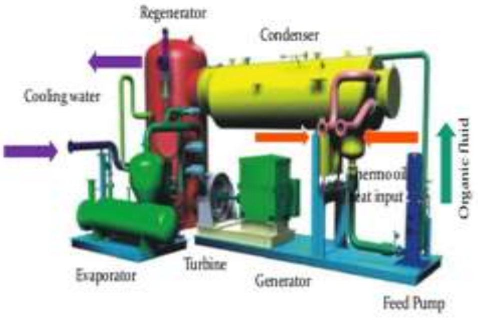


Fig-3: Trigneration System layout [4] **Fig-4: ORC components[7]**

C. ORGANIC RANKINE CYCLE (ORC)-Chen and Goswami [5] reviewed the different thermodynamic systems for utilization of discard heat, like Organic Rankine Cycle (ORC).The ORC applies the principle of the steam Rankine cycle, but uses organic working fluid with low boiling points, instead of steam, to recover heat from a lower temperature source. The cycle consists of an expansion turbine, condenser, a pump, a boiler and a superheated (provide superheat is needed).Different form of combined with ORC as a bottoming cycle,ORC with different pure working fluids such as HCFC123 ($CHCl_2CF_3$), PF5050 ($CF_3(CF_2)_3CF_3$), HFC-245fa ($CH_3CH_2CHF_2$), HFC-

245ca (CF_3CHFCH_2F), isobutene ($(CH_3)_2C=CH_2$), n-pentane and aromatic hydrocarbons, have been studied for organic Rankine cycles. for power plants, cement industry, desalination, process industry,and manufacturing industry. Working fluid classified as a Dry fluid, wet fluid or isentropic fluid.Isentropic or dry fluid was suggested for ORC to avoid liquid droplet impingement in turbine blade during the expansion. If the fluid is too dry the expanded vapor will leave the turbine with substantial superheat, which is a waste and add to the cooling load in . The cycle efficiency can be increased using this superheat to preheat the liquid after it leaves the feed pump and before it enters the boilers [5,7-10] .All components of ORC shown in fig-4.

D. BINARY FLUID POWER SYSTEM(KALINAMODEL)-AleksanderKalina developed binary fluid based power and cooling system in between 1970 and 1980.Kalina cycles system (KCS) uses ammonia-water (Binary fluid) mixture based working fluidused as source for power and cooling. In this cycle ammonia is the refrigerent and water as is the absorbent due to the high difference in their boiling point and high enthalpy. In the Kalinacycle,the used binary fluid mixture results in a good thermal match in the boiler due to the non-isothermal boiling created by the shifting mixture composition.Several studies have shown that the kalina cycle performs substantially better than a steam Rankine cycle system.A second law analysis showed that by using a binary fluid,theKalina cycle reduced irreversibility in the boiler,resulting in improved efficiency of the cycle.One drawback of the Kalina cycle is the fact that high vapor fraction is needed in the boiler, however, the heat exchanger surface is easy to dry out at high vapor fractionas,resulting in lower overall heat transfer coefficients and a larger heat exchange area.Another drawback relates to the corrosivity ofammonia.Impurities in liquid ammonia such as air or carbon dioxide can cause stress corrosion cracking of mild steel and also ammonia is highly corrosive towards copper and zinc [5,29]. Goswami proposed in 1998 [5]a novel thermodynamic cycle that uses binary mixture to produce power and refrigeration simultaneously in one loop. This cycle,Fig-5a is a combination of Rankine power and absorption cooling cycle. The binary mixture first used was ammonia-water and later on new binary fluids were proposed and studied**.**

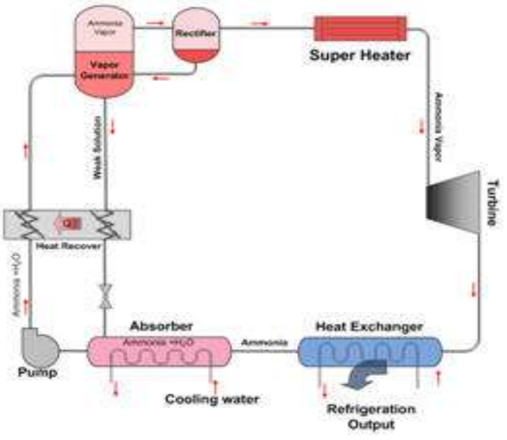


Fig-5a: Goswami Cycle [5]

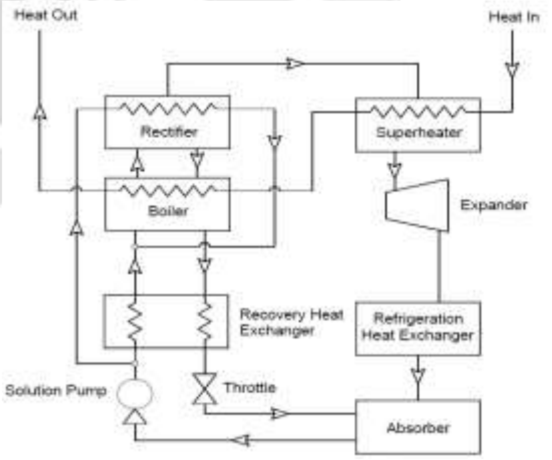


Fig-5b: Schematic of the power-cooling cycle [5]

III. WASTE HEAT ENERGY SOURCES AND TECHNOLOGICAL DEVELOPMENT

(Study by TURBODEN, project of centre of science and environment,GOI)

Three categories of wastage heat sources are distinguished with respect to the temperature level, low (<2300C),medium (230-650 0C) and high (>6500C)[3].Waste heat sites and thermal levels are listed in table I, and table II explain Indian industrial sector waste heat recovery survey by TURBODEN.

Table-I: Energy recovery and its sources [3,6]

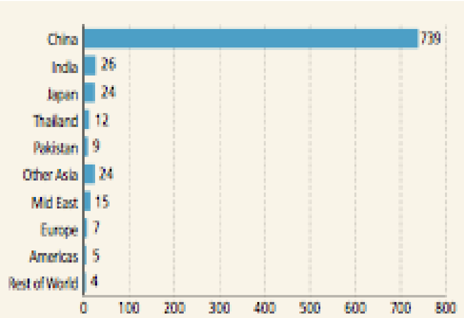
Heat Categories	Heat Sources	Temperature in ^{0}C	Suggested recovery technology
High Grade (>650^{0}C)	Solid waste	650-1000	Air preheating
	Nickel refining furnace	1370-1650	Steam generation for heating
	Copper reverberatory furnace	760-815	Thermoelectric and thermal PV
	Glass melting furnace	1000-1550	Heat exchanger for preheating
	Hydrogen plant	650-1000	Thermal PV
Medium Grade (230-650^{0}C)	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 (>230^{0}C)	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

Table-II: Waste Heat Energy recovery in Indian Industrial Sector survey[3]

Cement Industry	Glass Industry	Iron and Steel 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	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	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

3.1 GLOBAL AND INDIA MARKET OF WHR

There are over 850 WHR power installations in the world shown in Fig-6. China leads in the number of WHR installations—739, followed by India (26 WHR installations) and Japan (24 installations) [61].



Country	Remaining WHR Potential, MW	Growth in Cement Market, 2012-2014	Concerns Over Power Reliability, Y/N	Industrial Electricity Prices, US$/MWh	Political Stability and Absence of Violence (2012) *	Regulatory / Sustainability Drivers, Y/N	Existing WHR Installed Capacity	Feedstock Moisture Suitable for WHR, Yes/Average
Brazil	190 - 340	4.7%	No	120 - 170	47.9	Yes	None	Yes
Egypt	175 - 300	2.6%	Yes	50-70	7.58	No	None	Yes
India	500 - 900	12.4%	Yes	80	11.85	Yes	>200 MW	Yes
Mexico	170 - 300	-1.7%	No	117	24.17	No	None	Yes
Nigeria	70 - 130	21.1%	Yes	50-100	3.32	No	None	Average
Pakistan	50 - 100	-0.4%	Yes	130 - 170	0.95	No	>100 MW	Yes
Philippines	60 - 110	13.6%	Yes	80 - 145	14.69	No	>18 MW	Yes
South Africa	55 - 100	9.5%	Yes	80 - 150	44.08	Yes	None	Yes
Thailand	30 - 60	14.4%	No	50-100	12.80	No	>172 MW	Yes
Turkey	150 - 280	17.5%	Yes	100 - 150	13.27	No	>80 MW	Yes
Vietnam	165 - 310	5.8%	No	60 - 70	53.92	No	>11 MW	Average

Fig-6: Global WHR Power Stations **Fig-7: WHR in Eleven countries**

(Source File-http://www.iipnetwork.org/62730%20WRH_Report.pdf2)

The eleven countries were selected based on the robustness of their respective cement industries and cement markets, relative prospects for near and mid-term growth in their economies and cement consumption, and market factors that would drive consideration of WHR such as power reliability concerns, industrial electricity tariffs and environmental and sustainability initiatives. Figure-7 provides a summary of the market review of eleven countries in terms of WHR potential [61].

3.2 WHR COMPANIES WORKS IN INDIA

Transparent Energy Systems Private Limited is an Indian engineering and construction firm that has developed and patented an in-house technology for waste heat recovery systems for the cement industry. **Tecpro Systems Limited** is an Indian engineering, procurement and construction contractor active in the power sector including captive power plants for the Indian cement industry. In February 2011 Tecpro entered into a collaborative agreement with Nanjing Triumph Kaineng Environment and Energy Company to develop waste heat power projects for the Indian market. **Thermax** is an Indian supplier and engineering/constructor of energy systems including boilers and steam systems. Thermax entered into an agreement with Taiheiyo Engineering Corp ofJapan (a subsidiary of Taiheiyo Cement) to offer waste heat recovery power generation systems in India. The collaborative has two systems at JK Cement, Nimbahera and at JK Lakshmi [60-61].The installed capacity of heat recovery power generation systems for industry and renewable energy sources both in India using ORC described in table-III.

Table-III:ORC Development in India [61]

Sector	**Capacity (MW)**
1. Wastage Heat Recovery In Major Industry	
a. Cement	574.2
b. Glass	35.7
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**

IV. RESEARCH OVERVIEW ON WHR SYSTEMS

Present Literature review focus on low grade energy recovery systems, working fluid and their selection criteria with fluid properties and technological development. The working fluid is one of the most important components of a Rankine cycle power system. Intense research of non-geothermal ORC use took place in this country during the early 1970's through the early 1980's. ORC heat engines were reconsidered for utilizing solar resources and conserving other resources by recovering energy from waste heat. In one an ORC was integrated with a large truck engine to recover heat from the exhaust and save on fuel costs with the idea of replacing the automobile internal combustion engine with an ORC system was explored [16-17]. Mechanical cooling systems were one of the more productive research areas that dealt with the conversion of solar thermal energy. A significant amount of the publishedliterature regarding ORC conversion of solar thermal energy comes from this and related work [18]. The concept started as an alternative to solar-driven, absorption, air conditioning cycles which have a limited coefficient of performance. Essentially, mechanical work produced by a solar-driven ORC would be used to drive vaporcompression air conditioning equipment, with the potential of a higher COP than absorption equipment [18-20]. As for ORC technology today, it has found some niche successes in geothermal utilization, biomass utilization, some industrial heat recovery, and cathodic protection of pipelines, as judged by a few manufacturer'sportfolios. More recent research in the area has largely taken place internationally [21-24]. Two approaches have been noted: one is to develop and design systems around high-speed turbo-machinery with a shaft integral generator and circulation pump , thus reducing costs by simpler design, and the other, more recent idea is to adapt mass-produced (cheap) displacement compressors for use as reasonably efficient expanders [24-27]. The lineage that the power cooling cycle is derived from initially intended for utility-scale bottoming cycle duty. The first study of an absorption based power cycle was performed by Maloney and Robertson who concluded no significant advantage to the configuration. Several decades later, Kalina reintroduced the idea of an ammonia-water power cycle as a superior bottoming cycle option over steam Rankine cycles [28-31].Theammonia-water based power cycles have been proposed for solar utilization, geothermal, ocean thermal energy conversion, and other forms of heat recovery. While it was the interest brought about by Kalina's proposal that led to the introduction of the power-cooling cycle, it is somewhat ironic that the original suggestion for its implementation is more similar to the original Maloney-Robertson implementation [7,8].Referring to Fig-5a&5b of power-cooling cycle, basic solution fluid is drawn from the absorber and pumped to high pressure via the solution pump. Before entering the boiler, the basic solution recovers heat from the returning weak solution in the recovery heat exchanger.In the boiler, the basic solution is partially boiled to produce a two-phase mixture; a liquid, which is relatively weak in ammonia, and a vapor with a high concentration of ammonia. This two-phase mixture is separated and the weak liquid is throttled back to the absorber. The vapor's ammonia concentration is increased by cooling and condensate separation in the rectifier. Heat can be added in the superheater as the vapor proceeds to the expander, where energy is extracted from the high-pressure vapor as it is throttled to the system low-pressure. The vapor rejoins the weak liquid in the absorber where, with heat rejection, the basic solution is regenerated. [32-34]. Later studies concluded that the cycle could be optimized for work or cooling outputs and even for efficiency. Optimization studies began to appear, optimizing on the basis of various efficiency definitions, minimum cooling temperature, working fluid combination, and system configuration. Also, an experimental study was described byTamm and Goswami [10] which generally verified the expected boiling and absorption processes. Goswami and Xu [33] presented the first theoretical analysis of the power-coolingcycle. Turbine inlet temperatures of 400 – 500 K were considered along with absorption temperatures of 280 – 320 K. Cooling production suffered with increased turbine inlet and absorption temperatures, and benefited with increased boiler pressure. Many of the operating trends of importance in this work were introduced here. Optimization studies began to appear following this work, which identified the balance of effects that dictate cycle operation. Lu and Goswami [8] optimized the ideal cycle conditions using various objectives, work output, cooling output, first and second law efficiencies. All operating parameters, efficiencies, power/cooling output, etc., were found to decrease with increasing heat rejection temperatures. At high heat source temperatures, 440 K, no cooling was possible at conditions optimized for second lawefficiency. A contrast between work optimized and cooling optimized cases was provided. Important differences in the cooling optimized case versus the work optimized one were higher vapor concentration, lower turbine inlet temperature, low vaporization fraction (16.5 % vs. 91.2 %), and a lower basic solution concentration. Minimum cooling temperatures were also optimized, and a minimum turbine exhaust temperature of 205 K was identified under the assumptions considered [35]. The appropriate efficiency expressions for the cycle was tackled by Vijayaraghavan and Goswami [36]. Vijayaraghavan, et al introduced a satisfactory second law efficiency definition based upon ideal Lorenz cycle performance which accounts for sensible heat addition and rejection behavior. However, they concede that ultimately the value of work and cooling will be decided by the end application .Both first and second law efficiency analyses were performed for the cycle. A second law efficiency of 65.8 % was determined [36-38].The idealized model considered for largest source of irreversibility was found to be the absorber at all conditions considered; while at higher heat source temperatures the rectifier also contributed significantly less-than-ideal modeling began with Tamm et al, in preparation for the initial experimental studies [10,39-40]. The largest deviation from idealized simulations was due to the non-isentropic performance of the turbine. This relates well to the findings of Badr et al. ,who identified the expander isentropic efficiency as the single-most influential factor affecting overall ORC engine performance. Initial experimentation was reported [41-42]; however, turbine operation was simulated by an expansion valve and a heat exchanger. General boiling condition trends were demonstrated, for example vapor mass flow fraction, vapor concentration, and boiler heat transfer. Vapor production was less than expected and improvements to the setup were identified and implemented. Performance of the new configuration, still having a simulated turbine, was also reported [10].Vapor production and absorption processes were experimentally shown, and independent study of the power-cooling concept has been provided by Vidal et al [43].

V. OVERVIEW ON WORKING FLUIDS

Steam has shown its ability to serve as working fluid in high temperature power plants. In low temperature (≤200 ºC) or low-output power plants (≤10 kW), the use of water is not economically feasible [44-45]. Therefore, other fluids should be sought. Interest was found for refrigerants and some other fluids. These fluids are: Halons, hydrocarbons (HCs), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and natural fluids like carbon dioxide, ammonia, air, etc. Unfortunately, some of the above categories of fluids were phased-out or are to be banned soon by the international regulations, manufacturers of refrigerants, and researchers to look for new environmentally friendly fluids. So, new categories of fluids like zeotropes, azeotropes and other multi component fluids were born [46-47,56,57].The choice of the working fluid is very important as it determines the efficiency and the economics of WHR technological development on the basis of thermal properties like critical pressure, boiling point, specific volume, molecular weight,compatibility with material and environment safety tools GWP and ODP values [48-53].There are different sets of experiment done by the different scientist or scholars and they find the property of the working fluid which is shown in table-IV.

Table IV: Summary of Commercialized Working fluids [36,44-45,48-54]

S.No	***Chemicals***	***Physical Data***				***Safety Data***	***Environmental Data***		
		Molecular Mass (Kg/Kmol)	**Normal Boiling Point Temp (T_{bp}) in ^{0}C**	**Critical Temp (T_{criti}) in ^{0}C**	**Critical Pressure (P_{criti}) 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

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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 (Amonia)	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

VI. COMMERCIAL WASTE HEAT RECOVERY SYSTEM

A **recuperator**, recovering waste heat from flue gases, the heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. **Heat pipe** is a thermal energy absorbing and transferring system and have no moving parts and hence require minimum maintenance. Heat pipe can transfer up to 100 times more thermal energy than copper. The heat pipe heat recovery systems are capable of operating at 315^{o}C with 60% to 80% heat recovery capability. **Economizer** provides to utilize the flue gas heat for pre-heating the boiler feed water in boiler. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler. For every 22^{0} C reduction in flue gas temperature by passing through an economiser or a pre-heater, there is 1% saving of fuel in the boiler. For every 6^{0} C rise in feed water temperature through an economiser or 20^{0}C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel in the boiler unit. **Heat Recovery Steam Generator** is an energy recovery heat exchanger that recovers heat from a hot gas stream. It produces steam that can be used in a process (cogeneration) or used to drive a steam turbine (combined cycle). HRSG provides the thermodynamic link between the gas turbines and steam turbines in a combined-cycle power plant. All units shown in fig-8,9,10,11.

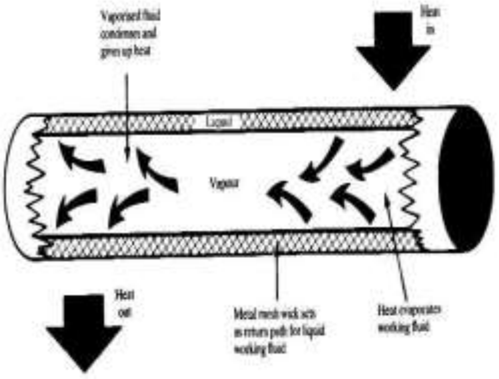

Fig-8: Heat Pipe Exchanger [4]

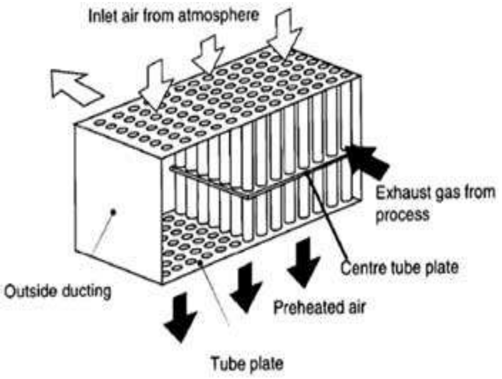

Fig-9: Recuperator [4]

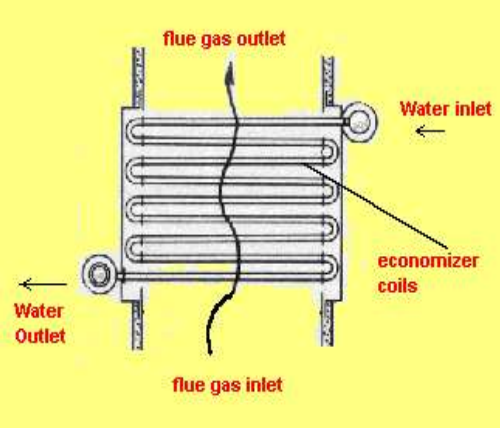

Fig-10: Economiser[4]

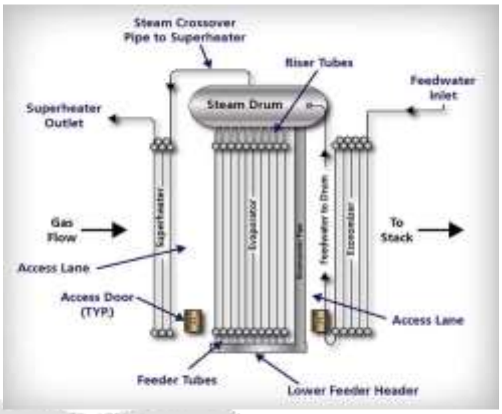

Fig-11: HRSG[58]

The literature review revealed the following-

- 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.
- From the literature, 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.
- Steam generation and metal forming processes consumes considerable amount of energy, even small energy saving can offer significant amount of savings in fuel consumption at a national level. However,such attempts are limited.
- Different Waste Heat Recovery Systems (WHRS) have been experimented to analyse the effect of various parameters of energy savings.

VII. CONCLUSION

- All thermal power plants emit heat during electricity, which can be released into the environment through cooling towers, flue gas, or by other means. By-product heat at moderate temperatures (100–180 °C, 212–356 °F) can also be used in absorption refrigerators for cooling.
- 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.
- There are lot of organic chemicals and refrigerants available in literature for power and cooling application in heat/energy recovery system. Most applicable 134a used in present technologies for energy recovery systems.R-1234ze and R-1234yf are Low global warming fluids available to replace R-134a in WHR technologies.

- Increased reliability and security of energy supply. Lower energy cost: the 75 % saving ofoperation cost compared to conventional unit and higher overall efficiency: 24 % higher than conventional unit.Fuel energy losses reduced to approximately 4 % as against around 28 % in case ofconventional system.
- The waste heat recovery from industries and power plant have huge potential for re-powering of plant and new market scope for employment of efficient heat recovery technology in respect of energy conservation and environment aspect.

ABBREVIATIONS

CHP-Combined Heat and Power
CCHP- Combined Cooling-Heat and Power
CHRP- Combined Heat Refrigeration and Power
GWP-Global Warming Potential
HRSG-Heat Recovery Steam Generator
IWH-Industrial Waste Heat
KCS-Kalina Cycle System
ORC-Organic Rankine Cycle
ODP-Ozone Depletion Potential
WHR-Waste Heat Recovery

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