Description of the two new thermodynamic cycles introduced in science and technology with inception of process invention for CPCE

Prolog

EVISA Engineering introduced two new thermodynamic cycles, both commenced in science and technology effective the patent for the process invention of CPCE. In addition, CPCE comprises a new modification of classic Rankin cycle for fossil fuel fired power plants and a modification of the Brayton-Ericsson cycle applied for gas turbine single cycle and gas turbine combined cycle as well.

The CPCE can be considered in two parts, one part is in conjunction with the carbon capture and separation via liquefaction from a CO_2 containing gaseous process media while this part encompasses the utilization of liquid CO_2 for heat recovery and power generation that is grounded on the first new thermodynamic cycle. The second part of CPCE is associated with high pressure combustion of hydrogen-oxygen for generation of Direct Steam via special torches and its superlative application to the super-efficient hydrogen based fossil power plants is founded upon the second new thermodynamic cycle.

As regards to the two new thermodynamic cycles, and in adherence to common custom and rite in the technical thermodynamics, every thermodynamic cycle is pronounced by the personnel name of the inventor who had invented, discovered and introduced the cycle to the technology. Hence that industrial cycles are all named by the personnel name of its inventor e.g. Rankin, Brayton, Diesel, Ericsson, Otto. Further on, Ericsson was the first engineer, who had invented two new cycles with broadened industrial application, termed to as the First Ericsson and the Second Ericsson cycle respectively. With respect to this usage, the EVIS-Engineering named the new cycles as the Bairamijamal First and the Second cycle.

The First Bairamijamal cycle is pertaining to availing any process working media, particularly liquid gases, more specifically, liquid carbon dioxide, embarked for heat recovery and power generation. The Second Bairamijamal cycle is entered by way of ultra superheated Direct Steam generation by a different thermodynamic path way than the Rankin cycle. This is also pivotal for facilitation of super-efficient power plant technology. In following, EVISA Engineering presents a short description on operation characteristics and its innovative idiosyncrasy of each cycle.

The two modifications were entered because of economically available hydrogen and oxygen, both in unprecedented financially affordable level. This modification is applicable for existing power plants based on Rankin cycle (for fossil fuel fired) and Ericsson cycles for gas turbine plants (single cycle or combined cycle).

I. The First Bairamijamal Cycle

This cycle is conceptualized for heat recovery power generation. The cycle comprises primarily the recouping of wasted heat, and optionally the sensible process heat in addition. Those heat sources are embarked in the thermal energy system for driving a working machine. The performed work of the power machine is either intended to drive a working machine e.g. pump, compressor and/or a generator. Therefore the system according to the working process media is ideally designated to recoup waste heat that is not deemed as sensible heat by heretofore cycles like with water as working fluid in the Rankin and Rankin/Brayton cycle.

For this purpose, by taking on the carbon dioxide as the working fluid, the cycle is consisting of a reservoir of liquid carbon dioxide, which is charged from the main CO_2 condenser. The CO_2 liquefaction is performed by supercritical cooling, capturing of CO_2, preferably by way of supercritical condensation, referred to CO2-CC section. The waste and process heat recovery is performed via CO_2 vaporization, superheating and supraheating[1] in the CO2-HR section.

The superheated/supraheated CO_2 is routed to the CO_2 turbine in the CO2-PG section. The set of CO_2 turbine comprises HP/MP/LP sections, driven with CO_2 working media via closed cycle, or preferably via semi-closed cycle, whereas part of the liquid carbon dioxide is extracted from the cycle to another purposes e.g. HPLTE-Syngas Generator while is replaced by make-up liquid carbon dioxide from CO2-CC section for CO_2 removal.

The waste heat recovery comprises any kind of wasted heat that is else dissipated from the thermodynamic system. The waste heat sources are process integrated heat sources e.g. downstream of chemical reactors, thermal processing and power generation like the off-steam downstream of the steam condensation turbine. These thermal energy streams are currently dissipated via cooling water, air cooler and wet cooling tower into the atmosphere.

For instance, the temperature level of the off-steam off the condensation turbine is in the margin of 120° C to 130° C under prevailing pressure of about 0.9 bar a. This part of thermal energy is dissipated usually down to the ambient temperature (typically in the margin 25° C to 30° C in average). Thus far, the dilapidation of those heat sources is independent on geographic and seasonal conditions, as far the cooling system is not restrained by its specific design capacity.

In order to conceptualize an economically profitable way for capturing carbon dioxide, it is essential to integrate any energy resources into the new system, so the final solution shall be feasible both from process economics and technically sound processing as well. This solution is achieved through capturing of carbon dioxide via condensation of CO_2, then harnessing it by way of the First Bairamijamal cycle for driving the generator and compressor involved for CO2 removal (i.e. Flue Gas and syngas compressor).

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[1] The term supraheating is ascribed to CO_2 cycle in analogous to ultra superheated steam

a) Operation field of the First Bairamijamal Cycle

The First Bairamijamal cycle is illustrated based on temperature-entropy chart. The capture of liquid carbon dioxide is carried out through cooling above the sublimation temperature line at the prevailing pressure, preferably above the critical temperature of 31° C and critical pressure of 74 bar g. The diagram 1 represents this cycle in a temperature-entropy chart, applied for subcritical undercooling, subcritical-supercritical vaporization and supraheating, then supercritical CO_2 condensation without interfering into the two phase zones. At ease of illustration, the reheating stages are not depicted in this diagram.

Further, the circulating mass flow of carbon dioxide in this cycle comprises typically 3 to 10 times of the mass flow rate of the excess liquid CO_2 to the HPLTE-Syngas Generator, even tough the two mass flow rates are hermetically separated. The obtained excess liquid CO_2 out of the first cycle is further processed to HPLTE-Syngas Generator.

The cycle commences with liquid CO_2 downstream of main condenser by isobaric at point 1. As regards to make-up carbon dioxide, this step is presenting CO2-CC section of CPCE processing. The system is distinctively characterized by following stages:

Step-1: Isentropic pressure elevation of liquid CO_2 by use of high pressure pump along the trajectory 1 – 2 to the isobaric line e.g. 300 bar g isobaric that is optionally carried out polytropic as regards to CO_2 pumping (i.e. jacket and shaft cooling of the pump or any other pump specific requirement).

Step-2 Isobaric sub-critical preheating of liquid CO_2 carried out below the critical point and upstream of vaporization along the lane of the 2 – 3. This step resembles the economizer in classic Rankin cycle. The step 2-3 is carried out by waste heat recovery with a waste heat source that performs the preheating of the liquid CO_2 for the steps 3-4. This step represents part of the CO2-HR heat recovery section of CPCE.

Step-3: Isobaric vaporization and superheating of CO_2 from subcritical condition over the critical point to supercritical region along the trajectory 3 – 4 routing from the left side of the critical point up over to superheated area, that is performed for instance as follow:

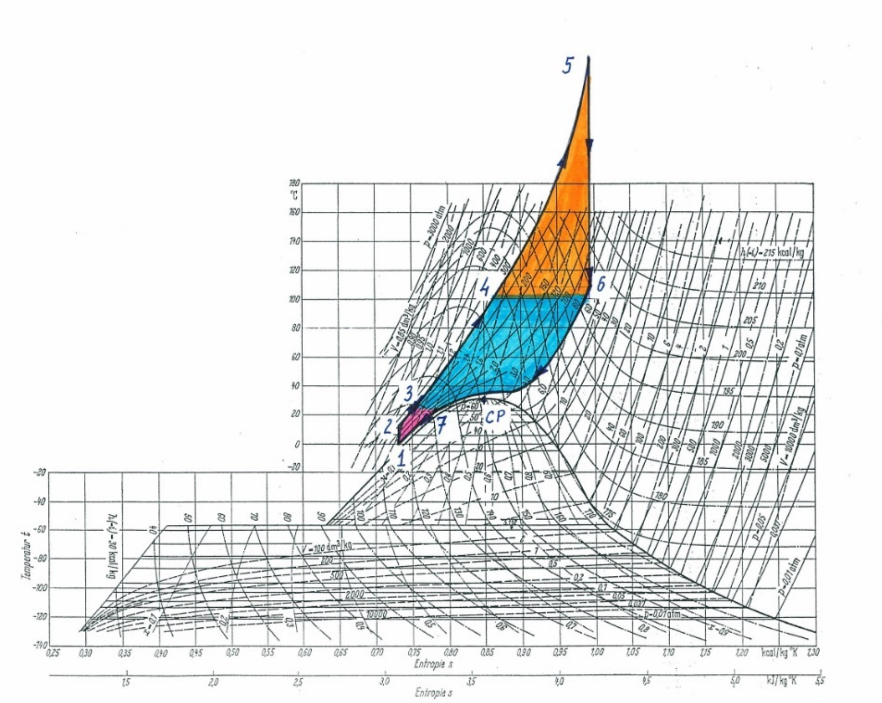

Diagram 1: Temperature-entropy chart for First Bairamijaml cycle illustrated with supercritical heating and supercritical condensation

i) Preheating and vaporization is carried out by wasted heat sources, e.g. intercoolers of the compressors employed in the site (e.g. Flue Gas scrubber heat exchanger and Flue Gas compressor of conventional fired power plants, LP/MP syngas compressor from gasification section, etc.), steam downstream of steam turbine, and process gas cooling. This step represents also part of the CO2-HR heat recovery section of CPCE.

ii) The regenerative heating by way of CO_2 heat exchange (Blue field in diagram 1)

The source of the vaporization heat can be, typically up to a margin of 100° to120° C. The heating media can be e.g. the off-steam downstream of steam turbine, or any other low temperature process heat. Preferably, this heat source can be also in part the regenerative heat of the CO_2 stream downstream of CO_2 turbine (along the path 6 – 7).

Step-4: Further isobaric CO2-HR superheating, referred to as supraheating, along the trajectory 4 – 5, to any temperature, typically 300° C to 600° C, for instance. Any source of process heat can be employed for CO_2 supraheating (e.g. process heat in combustion chamber, hot syngas of gasification, Direct Steam heating, etc.)

Step-5: Isentropic expansion of supraheated CO_2 along the trajectory 5 – 6, whereby the HP and MP sections of a backpressure expander CO_2 turbine are employed that release the supraheated CO_2 down to lower pressure. According to optimal heat-work balance, the backpressure can be kept close over the critical point (for instance in summer season or lower in the winter season, diagram 2). This section of the cycle is distinguished in CPCE processing as CO2-PG.

Step-6: Isobaric regenerative heat exchange from superheated CO_2 over the critical point to subcritical area for liquid CO_2, 6 – 7, whereas the regenerative heat exchange takes place for instance:

i) Preheating of cold process media i.e. HP/MP/LP gaseous products of HPLTE-Syngas Generator up/downstream of syngas and oxygen back pressure expander turbines, whereas one and the same product can be availed multiple of time for heat recovery from the CO_2 cycle.

ii) with LP/MP-steam generation consumed and condensed within the process for various plant internal purposes

iii) Preheating of other process media that are inherent part of the plant site

iv) Residual middle temperature cooling of the system by employing of dry air cooler accommodated in favor of preheating of internal cold process media, see below.

v) Preheating of desuperheating water for injection into hydrogen-oxygen combustion stream (employed in Second Bairamijamal cycle)

This step comprises the supercritical-subcritical condensation of CO_2. Under this condition a minimal of condensation heat is to be performed in order to transfer the gaseous CO_2 into the liquid aggregate of state without trespassing of the two phase zone that requires higher condensation energy. This field of operation is designated for summer season, or for regions with higher annual ambient temperature

Step-7: Isobaric undercooling along 7-1 of liquid CO_2 below 31° to 10° C, the acceptable temperature by high pressure pump, whereby a partial vaporization within the pump is safely oppressed. The undercooling depends on final outlet pressure of the pump about 250 to 300 bar g. The undercooling is illustrated in diagram 1 along the line 7-1 (in diagram 2, respectively along 5-1). The cooling down to this field of temperature can be executed by way of partial expansion of liquid CO_2 and recompression of gaseous CO_2 (termed in CPCE as ACU: Auxiliary Cooling Unit).

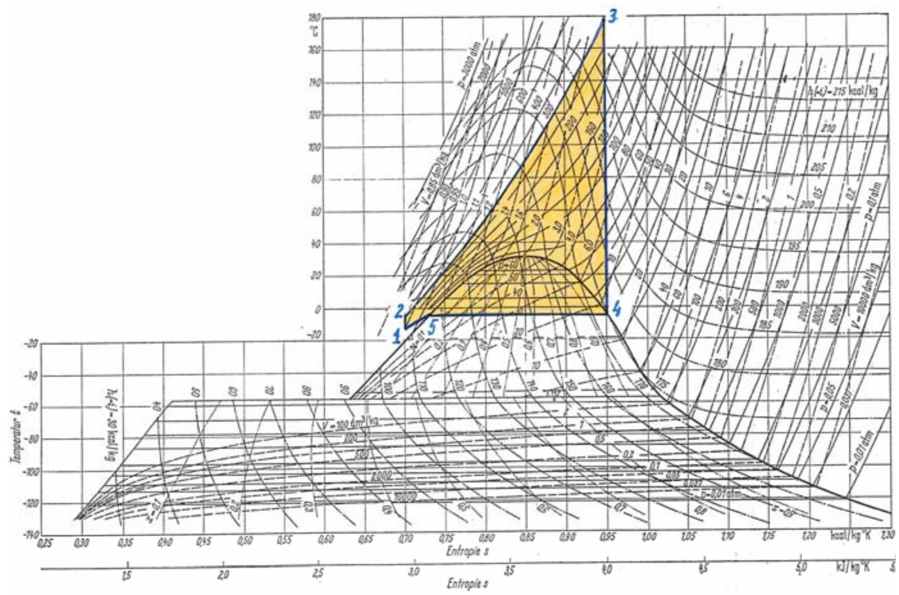

Diagram 2: Temperature-entropy chart for First Bairamijaml cycle illustrated with supercritical heating and subcritical condensation in the two phase zone

The diagram 2 represents the operation of this cycle with HP and MP CO_2 expander turbines without reheating. This diagram demonstrates the condensation of CO_2 downstream of MP turbine section that is considered via dry air cooler for cold region or winter season.

Specifically, the CO2 cooling and condensation is considered by preheating of oxygen and syngas obtained downstream of HPLTE-Syngas Generator and/or the preheating of those working fluids upstream of each turbine section. This measure is pivotal for First Bairamijamal cycle and CPCE for reason of high thermal energy efficiency. The four stage-preheating of oxygen in a pressure-enthalpy chart for oxygen in diagram 3.

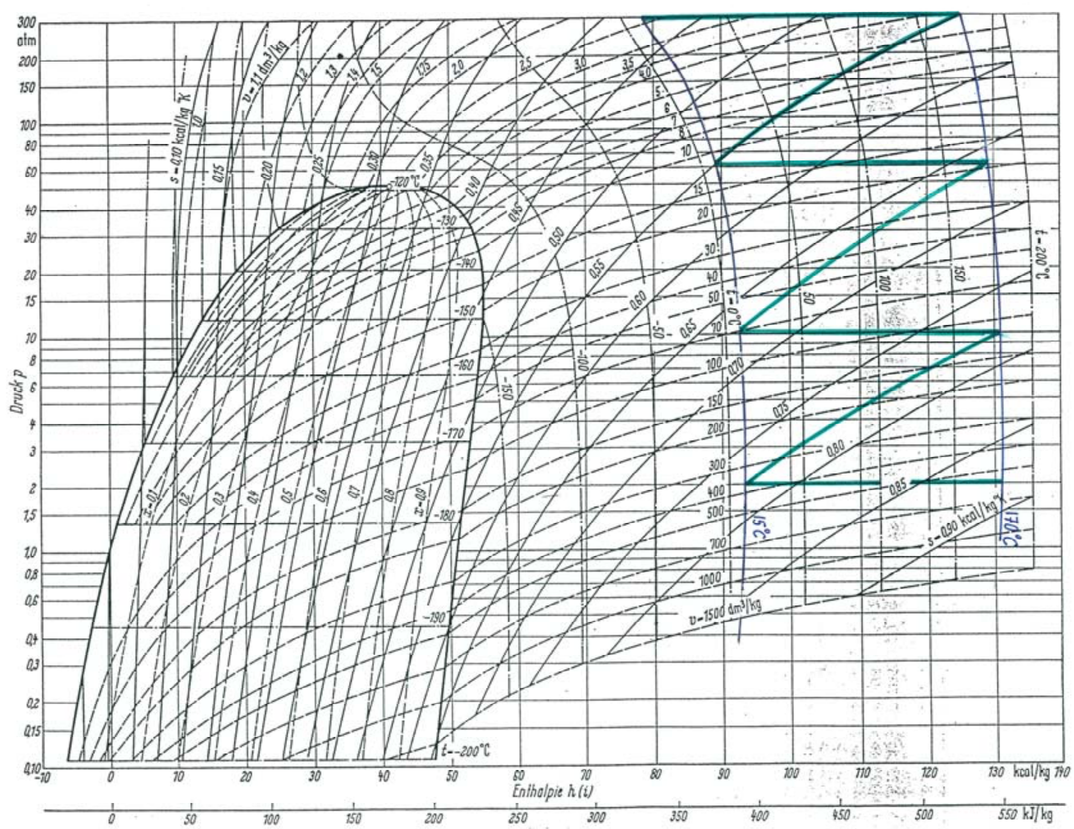

Diagram 3: Preheating of anodic oxygen upstream of oxygen turbine sections, upstream of oxy-fueling. The preheating is considered in the temperature margin of 15° C to 170° C in counter-flow to CO2 stream downstream of CO2 regenerative heat exchangers of CO2 cycle.

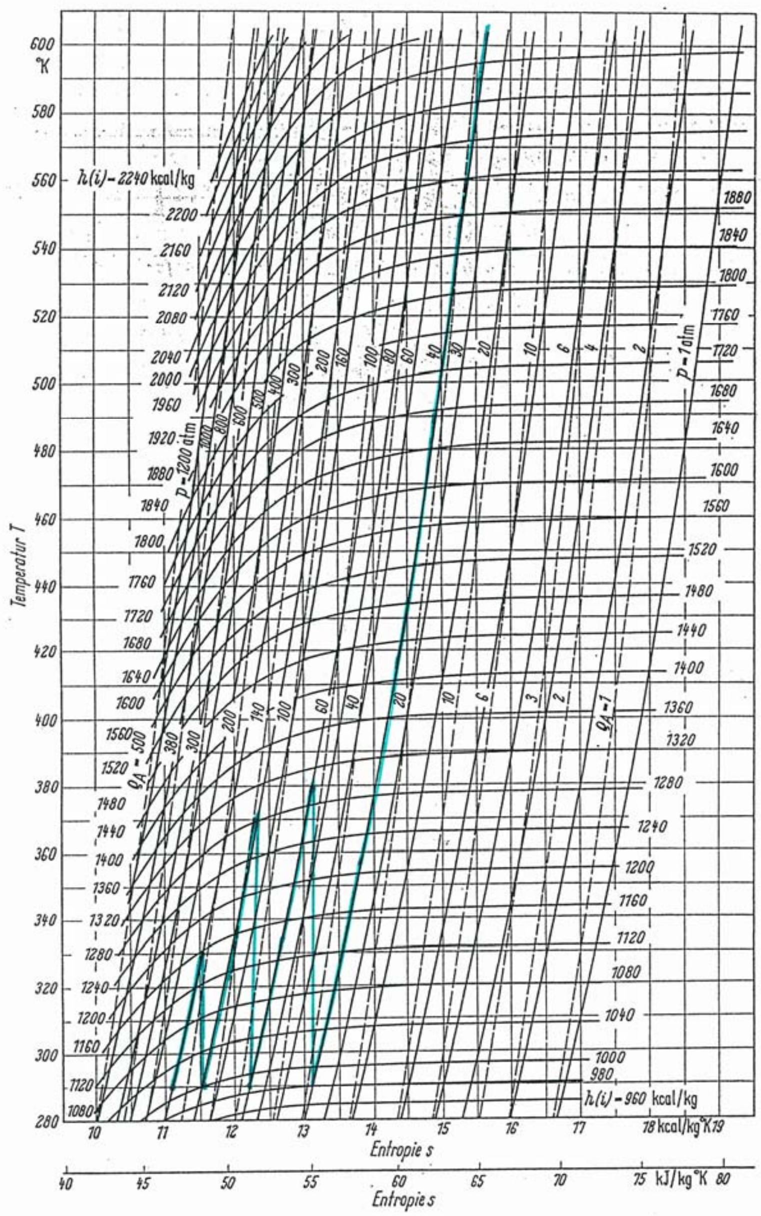

Diagram 4: Four stage preheating of cathodic hydrogen of syngas upstream of syngas turbine sections, and upstream of syngas delivery point for syngas converting to final products. The preheating is calculated in the temperature margin of 15° C to 325° C in counter-flow to CO2 stream downstream of CO2 regenerative heat exchangers of CO2 cycle.

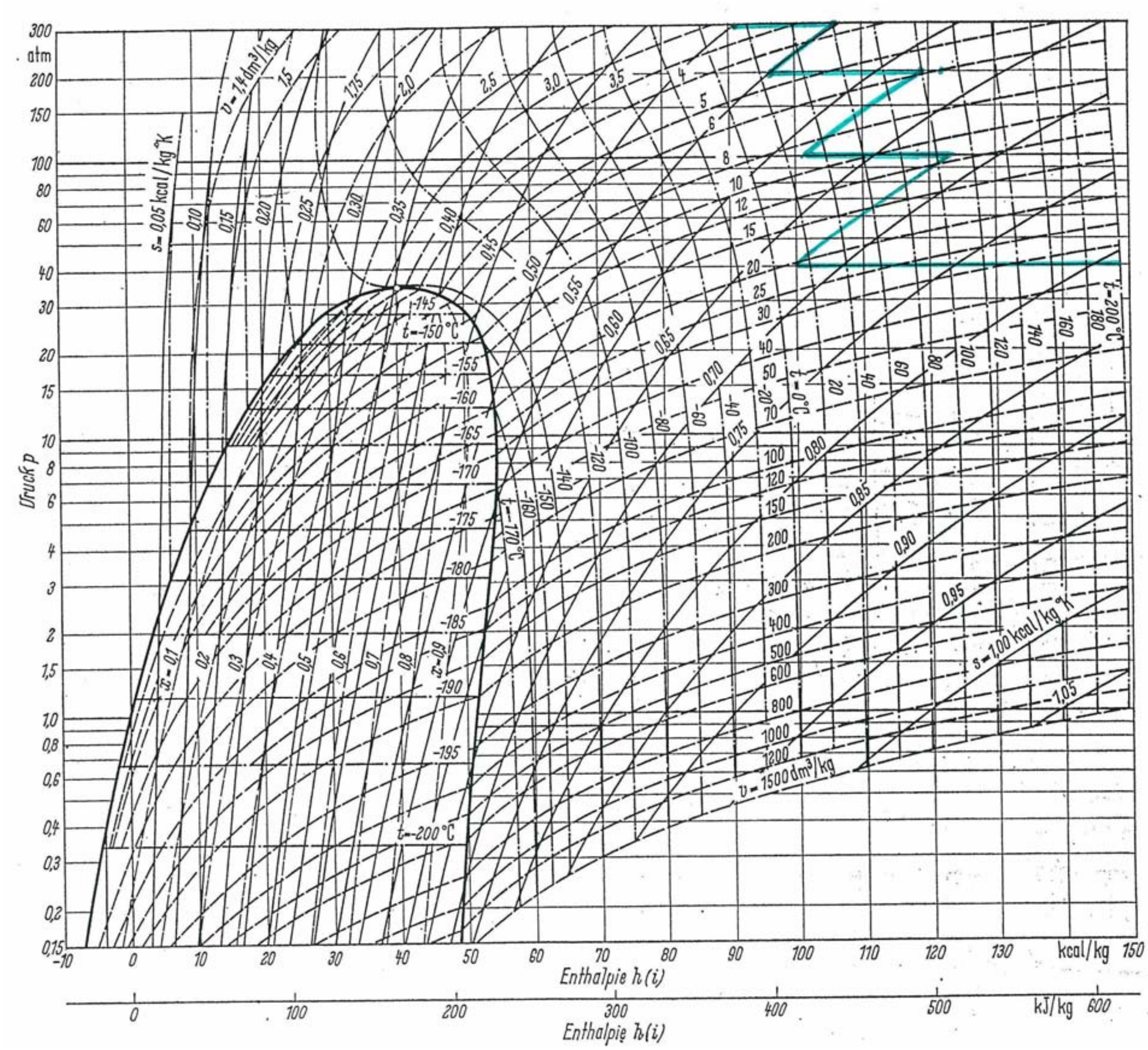

Diagram 5: Four stage preheating of cathodic carbon monoxide of syngas upstream of syngas turbine sections.

b) The characteristic features of the First Bairamijamal Cycle

From thermodynamic aspects, the first cycle is recognized by some characteristic features that are conducive for some poignant advantages, which can be summarized schematically below:

i) The pressurized process media is preheated and superheated starting from point 2 at the left side of the critical point. The transformation of liquid phase from the subcritical area to the gaseous phase into supercritical region is performed without the interfering of the two phase zone

ii) The preheating and superheating process is recognized by the routing of the isobaric trajectories left of the critical point, which are favorable by a steep upwards routing way along 2-3-4-5 routing isobaric trajectory. Respectively, the enclosed area, spreading out by the cycle is greater, compared with an area that is captured by trespassing of the two phase zone, that would reach out to the same final temperature at the same isobaric pressure (this characteristic routing of the isobaric lines are more conspicuously illustrative in the diagram 3 for the water system)

iii) The isentropic expansion of the superheated/supraheated working fluid (shown in orange) from 5 over the expander turbine is carried out down to an isobaric line, preferably above the critical pressure isobaric, so the condensation requires first a minimum of enthalpy change at one hand, while at the other hand a regenerative heat exchange can be carried out in favor of higher efficiency.

iv) The regenerative section; typically along the isobaric 6-7 (shown in blue area) is considered for preheating various internal media, ancillary LP steam generation, air cooler for cooling the CO_2 media. Further cooling agent for closing the cycle can be executed with the cold gaseous products from HPLTE-Syngas Generator, whereby the CO_2 isobaric “slips” from supercritical area over the critical point to subcritical area, with a minimum change of the enthalpy.

v) Further undercooling of liquid CO_2 prior to the high pressure pump is designated e.g. by partially vaporization of the CO_2 and re-compressing of it back to the cycle.

c) The advantages of this cycle from processing and mechanical design aspects

The characteristic features and advantageous this cycle from processing and mechanical design shall be described as follows:

i) This cycle allows the reuse of the most part of the low temperature thermal energy which is otherwise wasted with other media like water into the atmosphere, e.g. via the cooling tower, chimney

ii) The additional point is in conjunction to relative high molecular weight of CO_2, for instance compared with water is about 2.4 times heavier, respectively higher potential of kinetic energy through the expander turbines (expressed implicitly in entropy kJ/kg.K).

iii) Due the “dense” routing of the isochors along the line 2-3-4-5, the required heat exchangers are distinguished with high heat exchange coefficient, leading to compact design and size of the equipment. That meets also the requirement for heat exchangers employed for the cooling along the line 6-7-1 too.

iv) The excess heat subject to remove out of the system, can be carried out at higher temperature, so dry air cooler can be installed for outbalancing of heat exchange, e.g. under variation of seasonal circumstances.

v) The regenerative cooling and condensation in this cycle is distinctively flexible with changes in season. For instance, minor part of liquid CO_2 can be released to lower pressure that provides significant cooling capability, this part is subject to re-compression, however. As a rule of dumb in extreme case, one part of released CO_2 can condensate 4 part CO_2 respectively.

vi) In conjunction with CO2-CC for separation of CO_2 by way of condensation, the CPCE replaces the large scale plant unit for AGR (Acid Gas Removal) by use of chemicals e.g. Selexol, Rectisol, which certainly is costly in investment and high in maintenance.

II. The Second Bairamijamal Cycle

With the CPCE process invention and nearly cost-neutral conversion of CO_2 by HPLTE-Syngas Generator, the availability of low costs high pressure oxygen is undergirded in an unprecedented cost effective feasibility. As the same token, the high pressure low costs hydrogen can be performed via gasification, more specifically HP gasification[2]. This proves fact, that the classic oxygen supply plant unit via cryogenic air separation, termed as ASU, is supplanted by oxygen supply through HPLTE-Syngas Generator.

These specific features for low costs hydrogen and oxygen had led to the concept of high pressure supercritical and/or ultra superheated Direct Steam generation that is obtained by direct combustion of hydrogen and oxygen with water injection (deigned for temperature control and desuperheating) along the isobaric trajectory of water. By this way the system doesn't interfere into the two phase zone. With this measure the ultra superheated, supercritical high pressure Direct Steam is generated in an extraordinary compact and efficient footprint, which provides number of far-reaching processing and mechanical design advantages, than via classic Rankin cycle for facilitation of ultra superheated steam shall provide it in future.

The Second Bairamijamal cycle, in comparison with the Ericsson-Brayton cycle (applied for instance in the HRSG section of a gas turbine combined cycles) or with the classic Rankin cycle (applied in coal/oil/natural gas fired power plants) performs the following specific advantages.

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[2] The term HP gasification refers to a gasifier operating at a higher pressure, so the cleansed CO_2 containing syngas upstream of CO2-CC shall be operational above the critical pressure of CO_2. Typically, HP gasification delivers downstream of CO water shift and CO2-CC section hydrogen at a pressure of 110 to 80 bar g. Thus the further compression of hydrogen up to 250 to 300 bar g doesn't require high compression energy.

a) Operation field of the Second Bairamijamal Cycle

The characteristic peculiarities of this cycle are presented on the temperature-entropy chart in diagram 3 (shown in orange and blue area together). Within this chart, the classic Rankin cycle is embedded (shown in blue area) for reason of differences too.

The system has the following typical stages:

Step-1: Sequential combustion of high pressure hydrogen with oxygen or oxygen/steam blend, whereas the high pressure hydrogen is performed by hydrogen compressor, which is obtained first by high pressure Gasification Island. The sequential combustion applies for the primary Direct Steam as well for reheating Direct Steam generation. The high pressure gasification plant island delivers a clean syngas at a pressure equal or higher than the critical pressure of CO_2, so the hydrogen is obtained downstream of CO2-CC and upstream of hydrogen compressor at least at 75 bar g pressure.

The sequential combustion for Direct Steam generation is performed by special hydrogen-oxygen torches, generating high temperature steam at the point 2' prevailing in the flame of the torch along an isobaric trajectory routing left of the critical point of water and above the critical isobaric of the water (for instance the 300 bar isobaric line). The point 2' is not depicted in the chart.

Step-2 Injection of temperature controlled water from point 1 and desuperheating of the flame steam and in situ generation of additional Direct Steam, whereas the point 2 is attained, close upstream of the HP section of the turbine.

Steps 3 to 8 Sequential release of Direct Steam through the typical arrangement of HP/MP/LP section of the steam turbine with individual reheating section, which is carried out by further hydrogen-oxygen combustion. The five turbine stages, spreading from two HP, two MP and one LP section are illustrated by the points 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10 schematically.

Step-9 LP Direct Steam upstream of the LP section of turbine from point 10 to 10'

Step-10 Partial or optionally total condensation of Direct Steam condensate along the line 10' to 1'' and reuse of the water for further purpose, whereby the undercooled steam condensate 1'' is further preheated to point 1 prior to injection.

b) The characteristic features of the Second Bairamijamal Cycle

From thermodynamic aspects, the second cycle is distinguished by four characteristic features for facilitation of ultra superheated steam in a different way than based ob Rankin cycle. The second cycle is summarized schematically as follows:

i) The Second Bairamijamal cycle is first commenced by combustion point of high pressure gaseous hydrogen and oxygen (e.g. injection of oxygen into the hydrogen stream), whereby the combustion is preferably executed along an isobaric trajectory -left of the critical isobaric- so neither a trespass of the two phase zone is entered, nor the isobaric passes through a plateau, which reduces the extent of cycle's covered area.

The combustion of hydrogen-oxygen leads to the point 2' that is usually in the temperature field of 1800 ° to 2200° C, hence not depicted in the chart. The prevailing high temperature is stable within the field of the flame only. By controlled injection of preheated water from the point 1, the position 2 at the chart is stabilized.

Along this trajectory a "shoulder" is encompassed that is conducive for higher thermodynamic efficiency of the cycle. This represents the first distinguishing advantages of the new cycle (additional area gained by the surrounding points 1-2-3-3'-2'-1).

ii) The second distinguishing characteristic of the new cycle is pertaining to high operation temperature points of this cycle (point 2, then the points 4, 6, 8, 10 after each re-superheating in the Orange field), which are conspicuously higher than the typical high temperature points of Rankin cycle for ultra superheated steam along the same isobaric trajectory (demonstrated by the points 3, 5, 7 and 9 in the blue field).

Therefore, the second characteristics are shown "Dimondale" areas orange color between the superheated points of the two cycles, namely the 3-4-5-5' and 5-6-7-7' and 7-8-9-9' in the diagram 3.

The points 4, 6, 8 and 10 above represent the re-superheating stages downstream of each turbine stages (in case of the new cycle, 5 stages between the HP section to LP turbine section). Respectively, the points 3, 5, 7 and 9 represent the 4 turbine stages in a classic Rankin cycle operational with ultra superheated steam.

The Rankin cycle shows in the diagram 3, one stage less than the new cycle, because the Rankin cycle works in all existing plants always in subcritical vaporization of water, whereby the superheating takes place in the superheater section downstream of the boiler section separately.

With the exception of the first isobaric of the new cycle, all other isobaric are intentionally chosen as the same one for Rankin cycle, determining the same design and working pressure in each superheated point in either two cycles. Thus this measure shall reflect the second distinguishing characteristic of the new cycle.

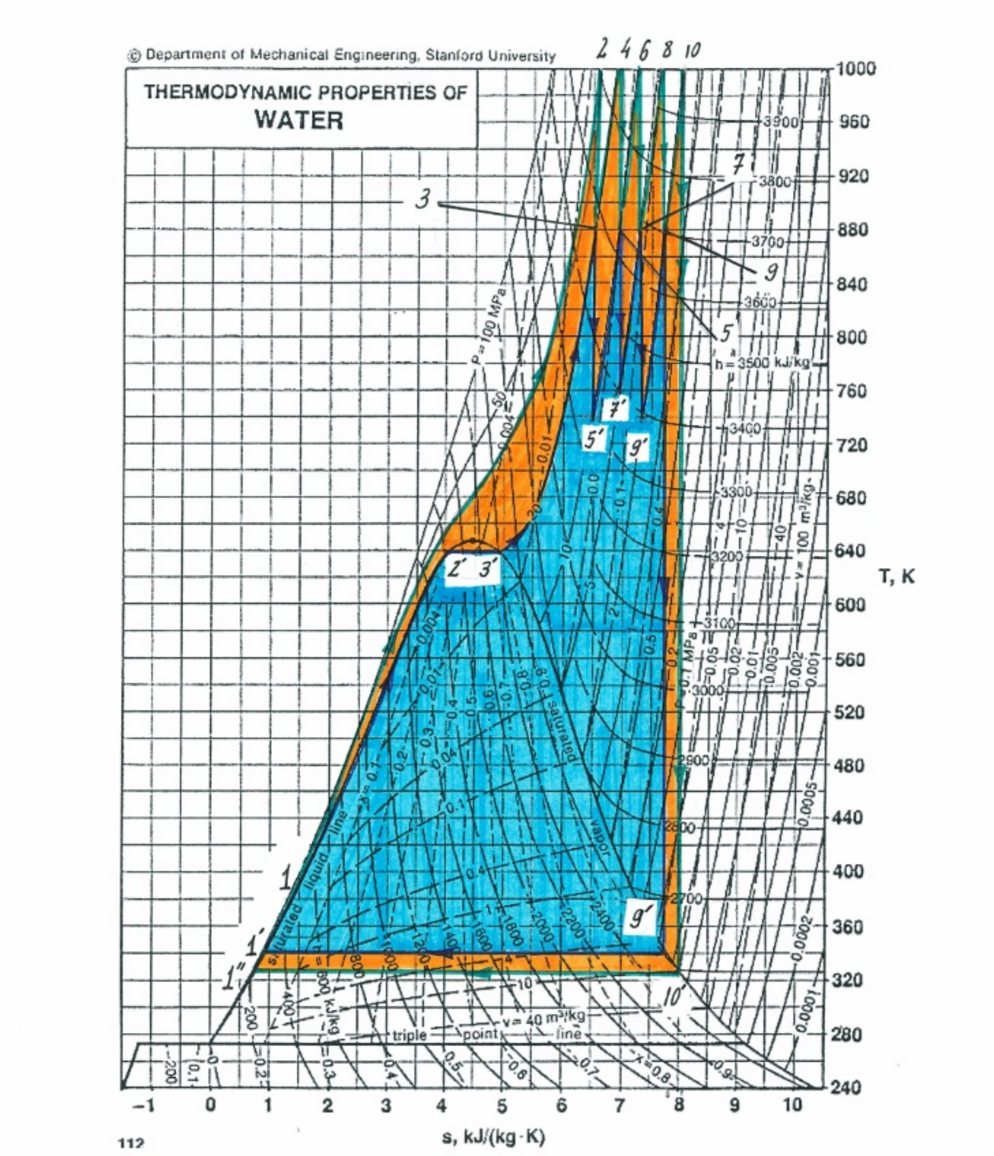

Diagram 6: Operation field of the Second Bairamijamal cycle shown illustratively by the depicted colored orange and blue area.

iii) The third distinguishing characteristic is associated with the last stage of the steam turbine section. In case of the classic Rankin cycle, it takes place from the point 9 (on the isobaric 9'-9-10), whereby the point 9' is reached downstream of the LP turbine section. The new cycle takes place from the point 10 along the LP isobaric 9'-9-10, whereby now, the point 10' is reached out downstream of the LP turbine section, which is lower than the 9' of Rankin cycle.

Compared with the Rankin cycle, the Second Bairamijamal cycle set a narrow "stripe" remained at the right side of the Rankin cycle, i.e. 9-10-10'-9'-9, that contributes also to an increase of the Second cycle's operation, respectively for higher thermodynamic efficiency in this subpart.

iv) The fourth distinguishing characteristic advantage of the new cycle is about the shifting the point 9' at the saturated line to lower point 10' in the new cycle. This shifting leads to a "band" along the off-steam pressure downstream of the steam turbine, gaining additional area through the new cycle.

In the classic water-steam closed Rankin cycle, the condensation line along the line 9'-1' corresponds to the "closing" of the cycle, carried out by cooling the off-steam via cooling tower by use of the circulating cooling water. The off-steam in the margin of 120° to 130° C is condensed, wherewith the steam condensate is obtained, that is subject to further processing (condensate polishing and recycling as boiler feed water into the cycle after chemical treatment, usually in active carbon filter, strong cation ion exchanger and mixed bed filter). The condensation heat is dissipated to the atmosphere. Thus the condensation via cooling tower in Rankin cycle (line 9'-1') overlays the "open" line of the new cycle along 10'-1''.

In the new cycle, the point 10' downstream of the condensation temperature is standing lower than 9' that would lead principally to greater condensation heat prevailing to lower pressure downstream of the steam turbine. However, the off-steam in the new cycle is obtained from chemically pure hydrogen and oxygen that can be even released into atmosphere without any adverse impact. By contrast to the classic water-steam Rankin cycle with carbon steel material in boiler, superheater section in conjunction with higher heat transfer coefficient, the Direct Steam generation is facilitated in a very compact design by use of stainless steel that is now affordable due significant smaller footprint.

From practically point of view, only part of this pure steam can be regained by way of condensation (e.g. via CO_2 cycle) in order to cover the demand for desuperheating water and the make up water for HPLTE-Syngas Generator.

c) The advantages of the Second Bairamijamal Cycle from processing and mechanical design aspects

The most advantageous of the Second Bairamijamal cycle can be summarized as follows:

i) Particularly, the highly costly and high maintenance gas turbine is out of the picture for super efficient fossil power plants.

ii) The Direct Steam generation is carried out at noticeably higher temperature than the steam generation via Rankin cycle for ultra superheated cycle.

iii) The point above is primarily founded on the basis of very small footprint that justifies the application of more expensive stainless steel material instead of extremely large scale boiler and superheating section of Rankin cycle with boiler vessel, circulation heat exchanger trials, steam drum and superheating trials.

iv) The huge boiler building is eliminated entirely. The generation of Direct Steam can take place in one or multiple arrangements of the torches in “pipe(s)” in about 250 to 350 feet upstream of the HP section of steam turbine’s intake nuzzles, or in equally distance along the re-superheating sections, respectively. Thus from investment point of view, the mechanical design of the system is tremendously reduced because of very compact footprint.

v) At the other hand, the applied material can be easily made of stainless steel, in order to regain chemically pure steam condensate without any kind of contamination or adverse impact to the environment.

vi) As result of Direct Steam generation, the chimney of indirect steam generation is eliminated. So the most accused element of the fossil energy for emission of harmful constituents e.g. mercury, antimony, flying ash, radioactivity from radioactive coal pollutants and Black Carbon emission (during the sooth blowing) doesn’t take place anymore.

vii) Other units, removed from the landscape of power plants, are cooling tower, large scale water softening, preparation of demi water and BFW are eliminated out of the scenery of the power plant as well.

Respectively, there are far less plant units and equipment subject for operation and maintenance.

III. Modification for Ericsson-Brayton Cycle in existing gas turbine power plants

As regards to retrofitting of the existing gas turbine power plants (both single cycle and combined cycle), the HPLTE-Syngas Generator of CPCE performs extraordinary opportunity for repowering.

Both products of HPLTE-Syngas Generator, the syngas from cathode as hydrogen supplier (after water shift conversion of CO to CO_2 and removal of CO_2 through CO2-CC and its recycle back to HPLTE- Syngas Generator), and the oxygen from anode, can be integrated in the gas turbine operation cycle.

The integration of oxygen into the intake air, typically known as oxy-fueling, leads to a release of intake air compressor of the GT. This option is advanced further by CPCE, so the preheated oxygen downstream of back pressure oxygen expander turbine, (as pure oxygen or in a blend with steam) is to be fed into the combustion chamber of GT directly, so the air compressor of GT is either released in load or it can be de-clutched from the shaft. This kind oxy-fueling leads to higher output performance of the generator. Respectively, the repowering of the existing gas turbine power plant can be accomplished without harnessing of the oxygen supply plant through battery of cryogenic air separation plant units.

At the other hand, due to the fact that affordable hydrogen is readily obtained by HPLTE-Syngas Generator, a side stream of this hydrogen can be added to the fuel path of the existing gas turbine (downstream of fuel gas final filter; upstream of the ring distributor of GT). The addition of hydrogen into the fuel of conventional power plants, particularly into the fuel gas supply path of the gas turbine, is termed as co-fueling in the context of CPCE process. The co-fueling leads also to additional power, specifically if it is accompanied with steam injection in the combustion chamber of the gas turbine, which resembles to augmentation period of gas turbine operation.

IV. Modification for Rankin Cycle in existing fossil power plants

Like the addition of hydrogen into the fuel gas supply path of the GT, co-fueling can be executed in the existing conventional fossil power plants.

By this way, particularly accompanied with the state-of-the-art oxy-fueling, a higher output performance of the plant can be achieved. The CPCE encompasses as well the co-fueling of conventional power generation plants that is carried out as injection of hydrogen via hydrogen/steam injectors into the combustion chamber of boiler.