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HEAT RECOVERY SYSTEMS IN HOT BLAST STOVES PLANT: APPLICATIONS, TYPES AND INTEGRATION[1]

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Abstract
Since the beginning of the seventies at the latest the reduction of energy consumption of stove plants is one of the top criteria of construction. With the increase of energy prices, the price for gases of high calorific value rose dramatically. The hot blast stoves process allows the energy in the waste gas of the stove plant to be recovered in order to save energy. The recovered energy is used for preheating the combustion media and thus the consumption of high calorific gases (coke oven gas or natural gas) to achieve the required flame temperature can be reduced. Right from the beginning PWR&E (former DIDIER / DME) has taken this development into account and substantially participated in the development of heat recovery and preheating systems. Entirely different systems for new constructions as well as for existing plants were adapted to the special requirements of different hot blast stove plants.
Key words: Hot stoves; Heat recovery system; Energy saving.

SISTEMAS RECUPERADORES DE CALOR EM PLANTAS DE REGENERADORES: APLICAÇÕES, TIPOS E INTEGRAÇÃO

Resumo
Desde o início dos anos 1970 a redução do consumo de energia na planta de regeneradores tornou-se um dos principais tópicos do projeto. Com o aumento dos preços da energia, o custo dos gases de alto poder calorífico subiu drasticamente. Em seu processo, os regeneradores permitem que a energia liberada no gás de fumaça seja recuperada a fim de economizar energia durante a combustão. A energia recuperada é usada para o pré-aquecimento dos meios de combustão (ar/gás) e, portanto, o consumo de gases de alto poder calorífico (gás de coqueria e gás natural) para atingir a temperatura de chama exigida será substancialmente reduzida. Desde o início PWR&E (antiga Didier / DME) tomou este desenvolvimento como prioritário e participou substancialmente no desenvolvimento de sistemas de recuperação de calor e pré-aquecimento. Sistemas totalmente diferentes para construções novas, bem como, para as instalações existentes foram adaptadas para as necessidades especiais de diferentes plantas de regeneradores.
Palavras-chave: Regeneradores; Sistema recuperador de calor; Redução do consumo de energia.

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1 INTRODUCTION – ADVANTAGES OF THE HEAT RECOVERY SYSTEM

The main advantages of a heat recovery system are summarized in the following items:

- The total consumption of energy of the hot stove plant can be reduced by installing a heat recovery and preheating system.
- With the reduction of the calorific value of blast furnace gas due to more efficient furnace operation, it has become necessary to add high calorific value fuel (coke oven gas or natural gas) to maintain the desired hot blast temperature. The use of preheated combustion media can considerably reduce - and even eliminate in some cases - the need for these expensive high calorific fuels. Each stove plant requires a separate study to determine which preheating system will meet the required operational parameters with the lowest capital cost.
- In the most cases by the installation of a heat recovery and preheating system the distribution of energy for the whole blast furnace plant will be changed in a positive way.
- The lifetime of refractory lining in the lower combustion chamber and ceramic burner can be increased because of the elimination of condensed water from preheated combustion gas and less temperature fluctuations.
- Stove performance can be increased by operating stove on the upper temperature limits of the checker work. At the construction of new hot stove plants the capital costs can be decreased by building of smaller hot stoves with higher performance which are calculated for higher waste gas temperatures.

2 HEAT PIPE HEAT RECOVERY SYSTEMS

Combustion gas and combustion air are directly heated by heat exchangers in the waste gas of the stoves. The control of all temperatures is simply made via bypasses around the heat exchangers. Except the controlling valves in the bypasses there are no agitated parts. An example for a circuit of this type is given in Figure 1.

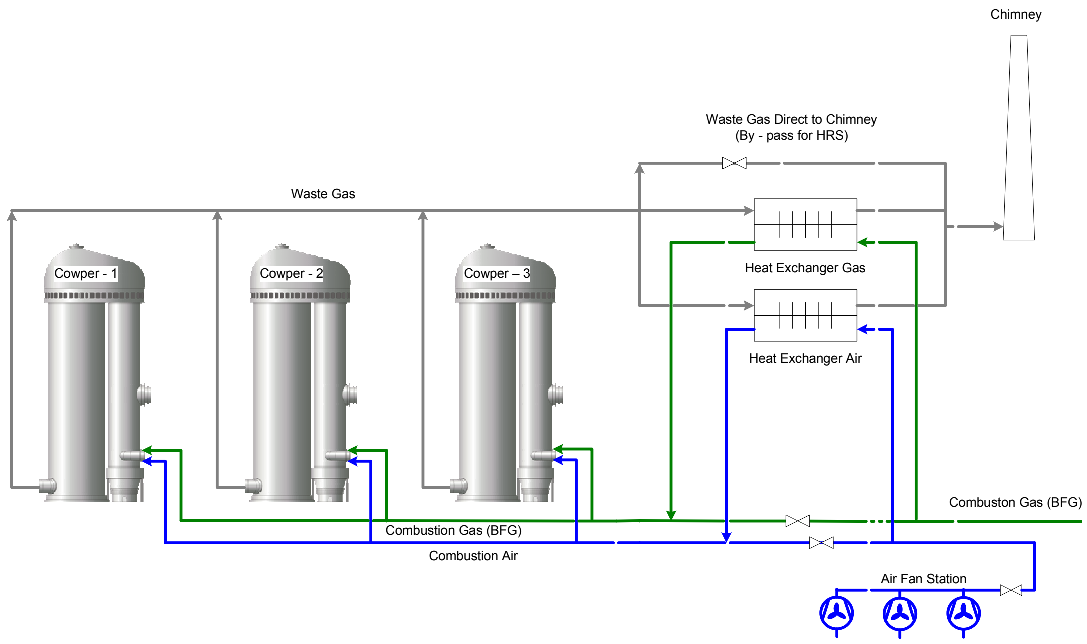

Figure 1: Process diagram of heat pipe heat recovery system.

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Figure 2 illustrates a 3D Model of heat recovery system for combustion gas, this system was build in Taiwan and running since years with very good performance.

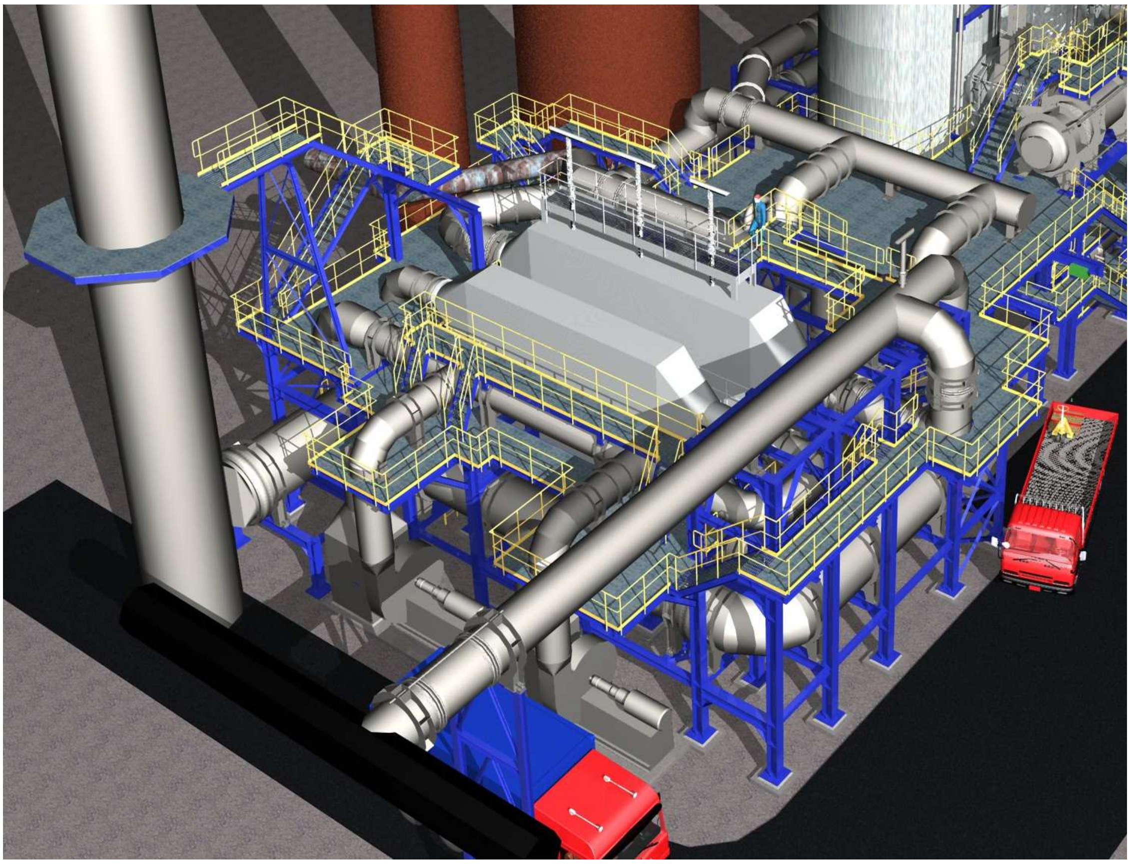

Figure 2: 3D model for heat pipe heat recovery system.

The Heat Recovery System, consisting of heat pipe modules, is especially suitable as heat displacement system between the hot waste gases and the cold combustion media.

Among the different available types of heat transfer systems, the heat pipe is one of the most efficient systems known today.(1)

The heat transfer takes place using the physical phenomena of evaporation and condensation. For this purpose, a pipe is evacuated, filled and closed off at both ends. When heat is applied the working medium (treated water), being in phase equilibrium, evaporates. The steam passes on to the upper cold pipe end where it condenses, giving off the heat of evaporation previously absorbed. The condensate flows back to the evaporation section below. The temperature of the working medium is maintained in equilibrium between heat absorption and heat disposal. The principle of heat pipes is schematically illustrated hereunder in Figure 3.

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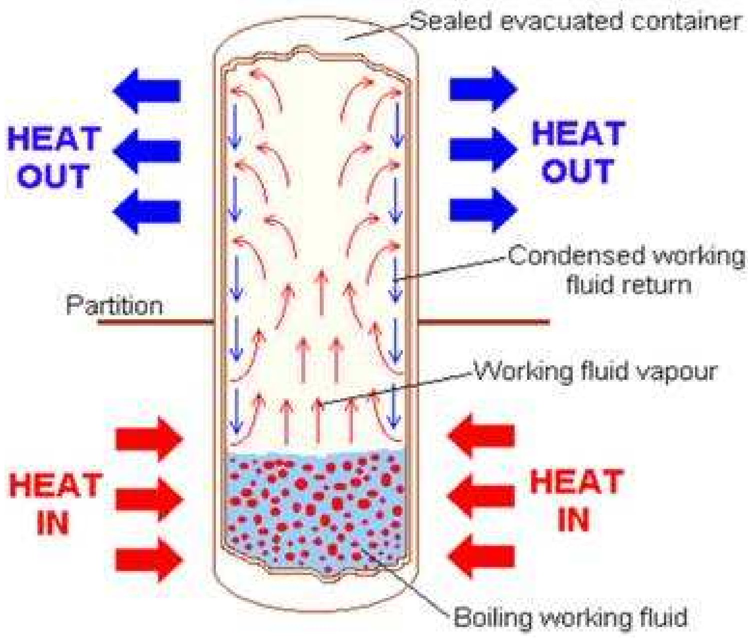

Figure 3: Heat transfer principle in heat pipes.

In order to utilize the high heat transfer coefficients due to the phase changes inside the tube for compact dimensions of the Heat Recovery System, finned tubes are used to improve the gas-side heat transfer due to their larger outer surface. The dimension of the tubes and fins are selected to achieve the optimum design taking in consideration all boundary condition. Also in selecting the pitch of the fins, PW takes in consideration the nature of the different medium supported with the long year operational experience with such system.

It is well known that carbon steel (the container material of HP) and water (the working fluid) react together and form iron oxide and hydrogen. The generation of hydrogen (non condensable gas) leads to the degradation of the heat pipe performance.(2) This problem is encountered by applying passivity formula to all heat pipes in order to provide a protection film on the inner surface of the heat pipes. Also as a part of the Paul Wurth quality, each heat pipe will be tested in work shop.

In the middle of the tubes between waste gas and combustion air part, a gas-tight partition wall is arranged. Several modules are arranged in series and / or side by side, depending on the efficiency requirements and gas mass flow. Paul Wurth system allows the replacement of individual heat pipes through threading connection across the separation plate. Paul Wurth heat pipe heat exchanger is illustrated in Figure 4. More details about the construction of Paul Wurth exchangers can be seen in Figure 5.

3 ADVANTAGES OF HEAT PIPES SYSTEM

The advantages of the heat pipes system are:

- simple plant geometry, compact design due to modular components (each of mounting);
- high operational safety due many independently working systems resulting in optimum availability;
- gas-tight, no leakage between the fluids;

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- minor pressure losses on the waste gas and combustion air-side saving of energy with the combustion air fans;
- no control and safety elements;
- realization of client - specific concepts by adapting the system to individual operating needs;
- no moving parts eliminating the need for propulsion energy. saving of energy with the combustion air fans;
- ease of inspections, through manholes and passage between the heat pipes modules;
- system is easily serviced since heat pipes can be replaced individually; and
- selection of materials to meet specific requirements.

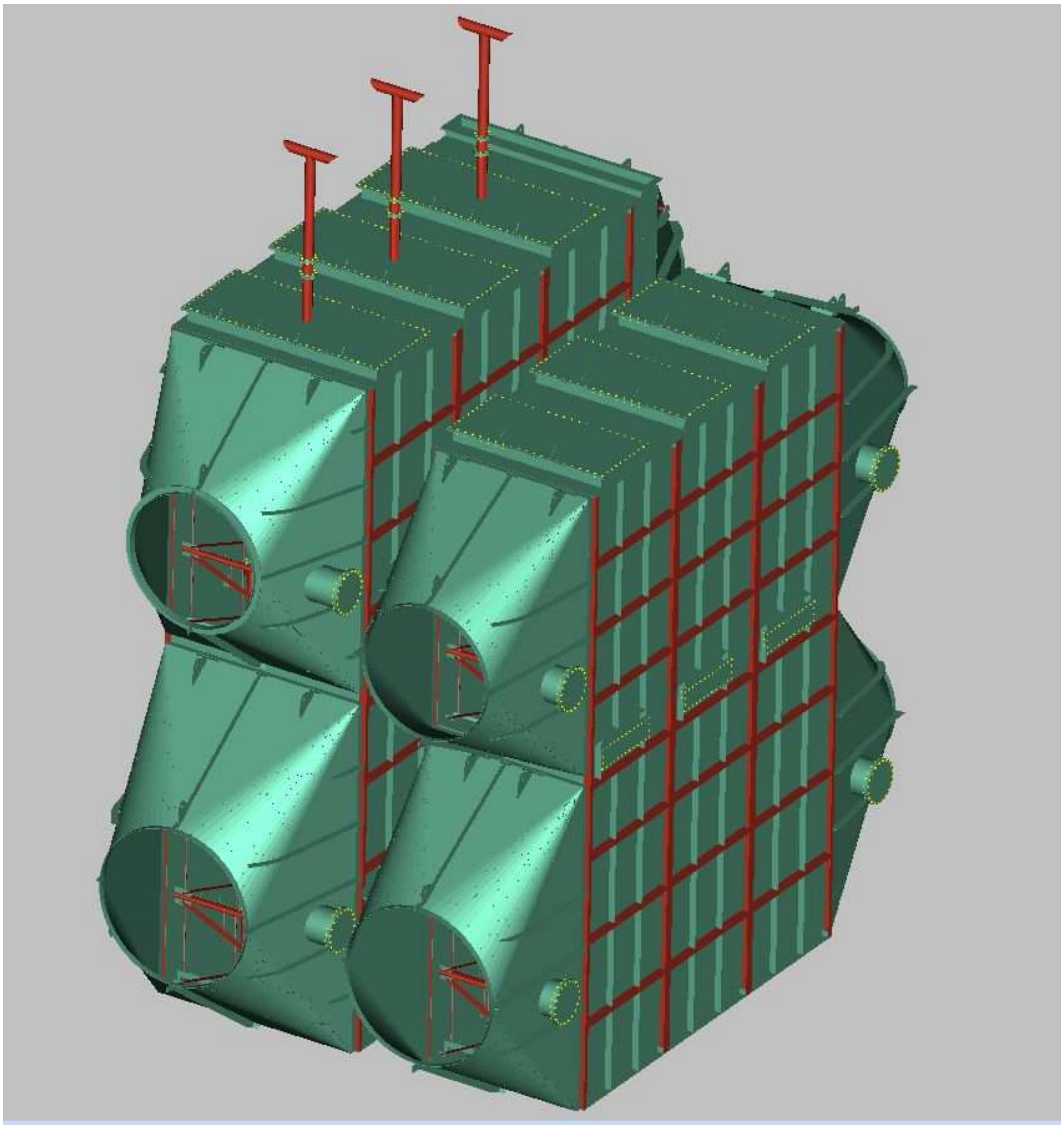

Figure 4: Paul Wurth heat pipe pre-heater for gas and air.

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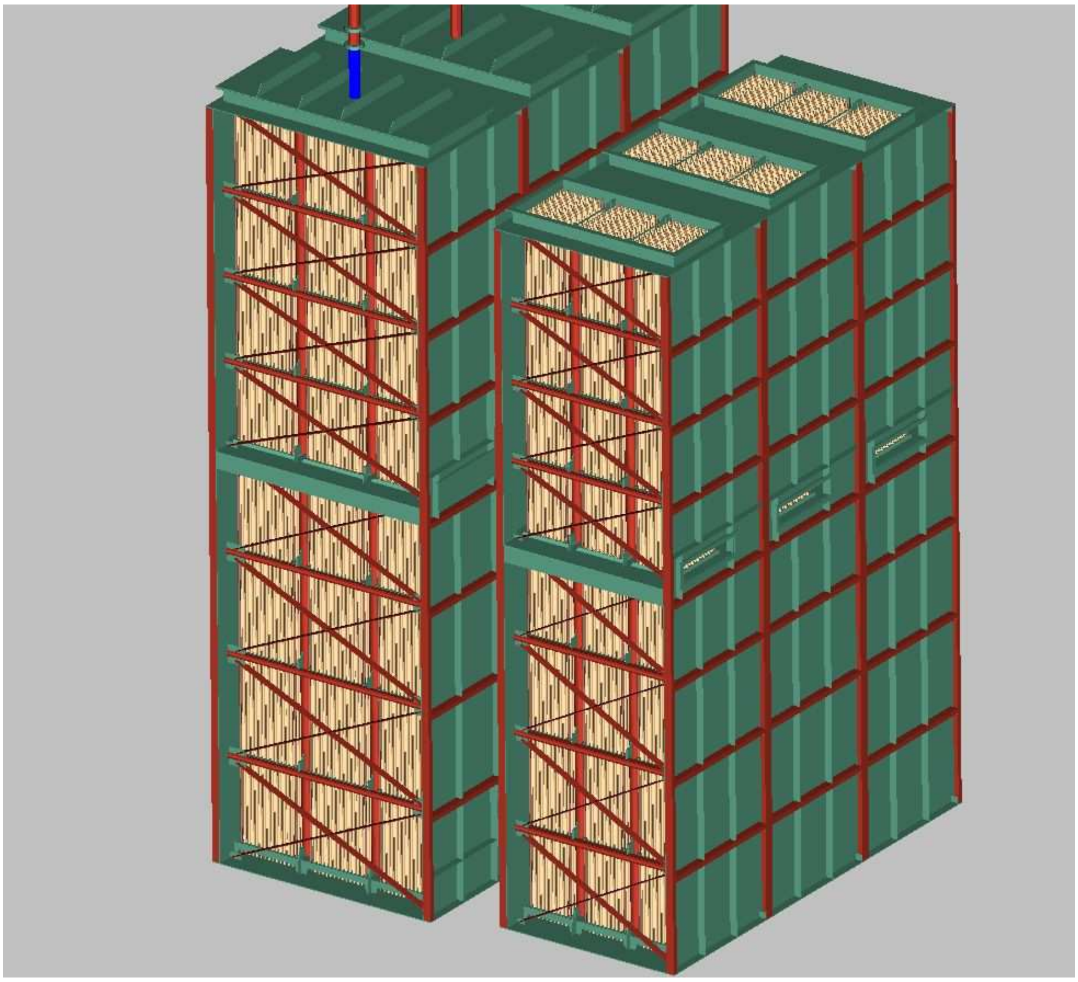

Figure 5: Stiffeners and heat pipes modules in Paul Wurth heat pipe heat exchangers.

4 MIST ELIMINATOR

In order to prevent the liquid droplets from being carried onto the heating surface of the heat exchanger, a high-duty droplet separator is mounted before the gas heat exchanger. The installation of the droplet separators has been made after successful tests on all plants constructed by PW and has proved satisfactory.
The separator sections are mounted in frame structures which are inserted as slide-in units from above into the casing. On front-side of the frames, a cover is provided for bolting to the casing. The separator includes spraying equipment for cleaning.
The mist eliminator can be of two types, wire mesh or lamella type; this will be decided during detail engineering. In selecting the size and type of mist eliminator the design of the mist eliminator allow the optimum selection between the separation capacity and the associated pressure drop.
The material of the mesh or the lamella is in general stainless steel to provide better resistance against corrosion.

5 HEAT PIPE HEAT RECOVERY SYSTEM WITH ADDITIONAL BURNER

Upon the request of the clients, the use of high calorific gases can be completely eliminated. This is achieved by using additional burner which produces additional exhaust gases to be utilized in elevating the preheating temperature of the

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combustion media to the required level. The exhaust gases from the auxiliary burner will be then mixed with the waste gases of the stove plant.
The auxiliary burner is fired using blast furnace gases. The flow diagram for such system can be seen in Figure 6. Figure 7 shows a 3D model of heat pipe heat recovery system with additional burner, this system is in operation since 2007 at China Steel Cooperation in Taiwan.

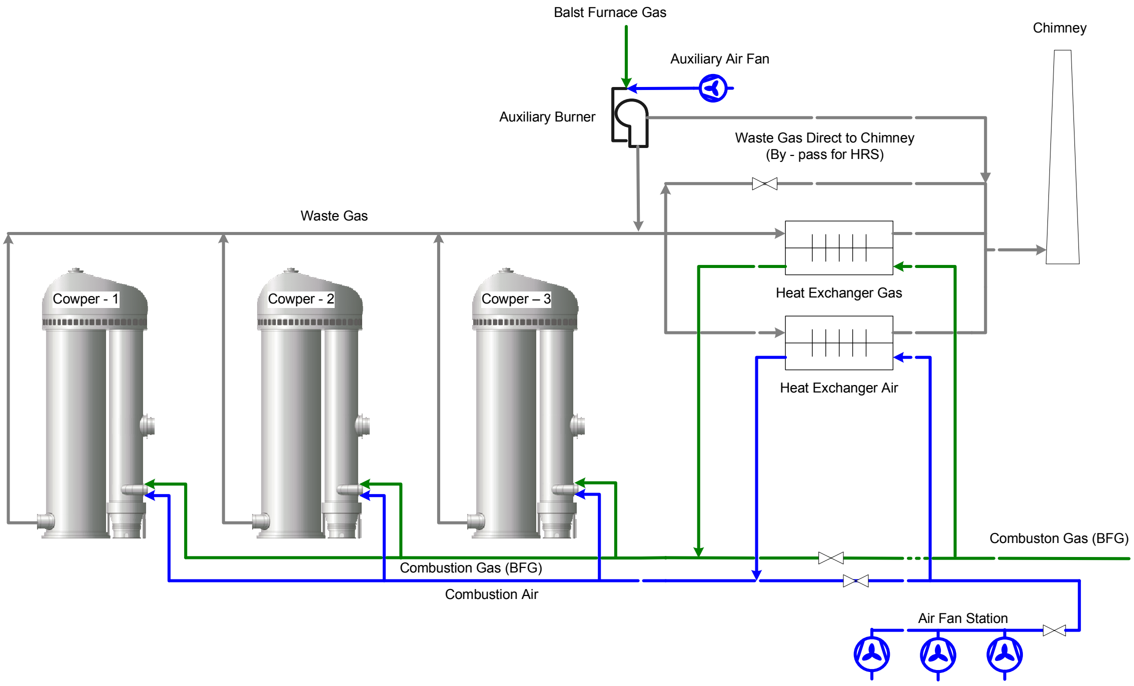

Figure 6: Flow diagram of Heat Pipe HRS with auxiliary burner.

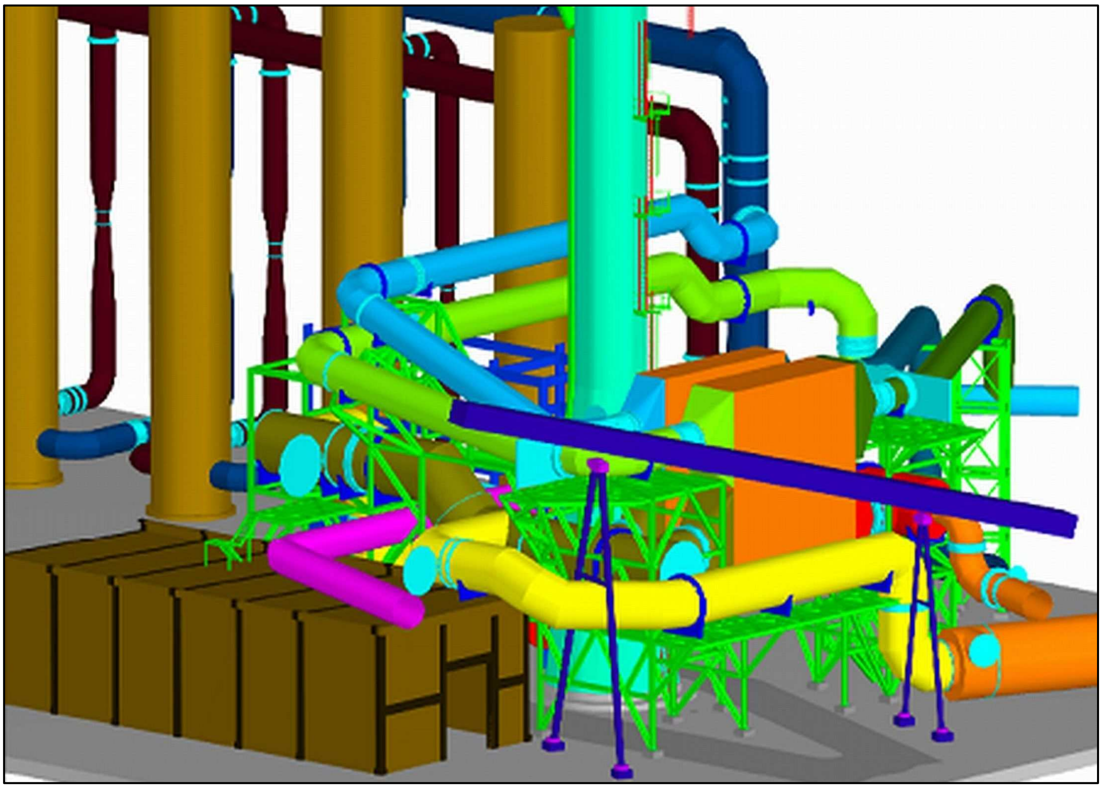

Figure 7: Heat Pipe Pre-heaters with additional Auxiliary Burner.

This system allows controlled hot blast temperatures of 1250 to 1300 ℃ without the use of gases with high calorific value at the usual calorific values of blast furnace gas of approx. 3000 kJ/Nm³.

6 SYSTEMS WITH HEAT CARRIER MEDIUM (OIL SYSTEM)

Here the energy in the waste gas of hot blast stoves is transmitted to a heat carrier in a heat exchanger. The heat carrier is carried back to the combustion media side of the stoves and there serves for preheating. Then the heat carrier is led back to the waste gas heat exchanger.
The preheating of combustion media can be made by individual heat exchangers in the branches for combustion gas and air directly in front of the stoves or in the collecting mains for combustion gas and air before the media are distributed on the branches.
Individual units in the branches are often suitable for existing plants, since they have smaller dimensions and integration thus is easier. They are particularly advantageous on the combustion air side, if there are individual combustion air fans for each stove. However, individual units also have disadvantages. The overall heating surface to be installed is bigger compared to heat exchangers which are centrally installed in the collecting mains, since it has to be installed also for the stove being on blast. During the blast period the corresponding individual units are not used. Moreover, the switching especially on the heat carrier side is complicated, since e.g. for a 3-stove-plant, 7 heat exchangers in all have to be controlled. Normally there is not sufficient space to bypass the individual heat exchangers on the preheating side.
The above description clearly shows the advantages of central heat exchangers. The disadvantages are only the larger dimensions and the slightly longer pipe which has to be insulated between preheating system and the stoves. The costs however, are lower in this case compared to the larger heating surface and to the extra equipment on the heat carrier side (pumps, control etc.) in the above case.
For new constructions Paul Wurth therefore always recommends to install central heat exchangers since here the required space can in most cases be taken into consideration when the layout of the plant is made. In the case of existing plants the available space within the plant itself has to be considered.
As heat carrier medium generally oil is used, rarely water. Since water evaporates at temperatures above 100 ℃ at normal pressure, but higher temperatures are required, such systems operate at higher pressures (at 180℃ the saturation pressure is already 10 bar). In Paul Wurth's opinion the extra expenditure for such pressure systems is not worthwhile.
Oil systems meanwhile continuously operate with oil temperatures of up to 350℃. This allows achieving theoretical temperatures of the combustion media up to approx. 310℃. Due to the usual limitation of the maximum waste gas temperature to values of 400 to 420 ℃ and the limitation of the waste gas temperature at the chimney by the dew point the waste gas of the stoves does not contain the energy required to achieve the above preheating temperatures. Without additional heating of the heat carrier medium or on the waste gas side of the stoves only approx. 210℃ to 230℃ will be achieved. Picture 8 gives an example for a preheating system with heat carrier oil and central heat exchangers.

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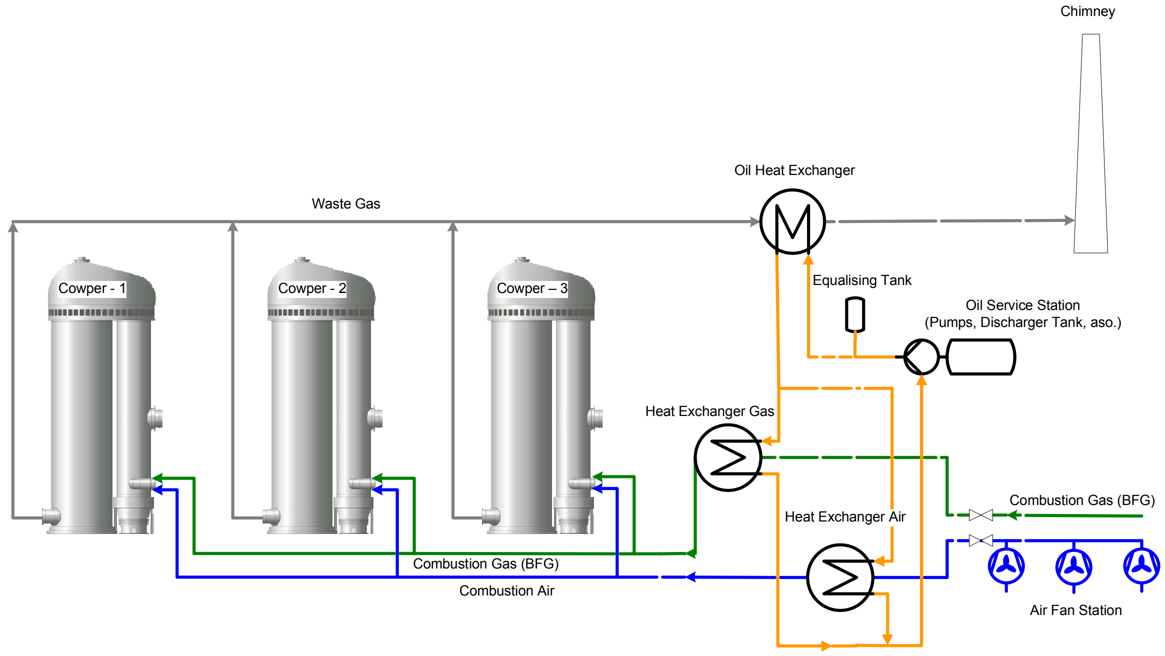

Figure 8: preheating system with heat carrier oil and central heat exchangers.

The inconvenience of all heat carrier systems is the limitation of the preheating temperatures to approx. 300 ℃ due to the heat carr ier medium. As a consequence the dome temperatures of 1350 ℃ and more requested today cannot be obtained with blast furnace gas alone. In most cases a gas

7 ILLUSTRATION CASE

The potential energy and cost saving when installing heat recovery system, is best illustrated using a case study. For a hot blast stoves plant with 3 stoves in operation we considered the following three cases:

Case 2:
This is the base case, without heat recovery system or preheating of the combustion media.
Case 2A:
Here we consider a preheating of the combustion media up to 180℃ each.
Case 2B:
Here also we have heat recovery system but we considered a preheating of combustion gas and combustion air up to 210℃.
All considered operational parameters are summarized in the table here under:

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Table 1. Operational data of hot blast stoves, with and without heat recovery system

Operational Data of Hot Blast Stoves (HBS)					
			Case	Case	Case
Pos.	**Denomination**	**Unit**	Case 2	Case 2A	Case 2B
I	**Operation Parameters**				
1	Number of Hot Blast Stoves	pcs.	3	3	3
2	Operation Mode	-	3 Stove Operation	3 Stove Operation	3 Stove Operation
3	Hot Blast Volume	Nm³/h	90000	90000	90000
4	Controlled Hot Blast Temperature	°C	1200	1200	1200
5	Hot Blast Humidity	g/Nm³	12	12	12
6	Dome Temperature	°C	1350	1350	1350
7	Cold Blast Temperature	°C	65	65	65
8	Blast Pressure	bar (g)			
9	Blast-/ Gas-/ Change Over Cycle	min	60 / 110 / 10	60 / 110 / 10	60 / 110 / 10
10	Mean Combustion Air Temperature to HBS	°C	35	180	210
11	Mean Combustion Gas Temperature to HBS	°C	35	180	210
12	Gas Enrichment Rate	%	9,63	3,90	2,86
13	Mean Waste Gas Temperature HBS	°C	273	273	310
14	Max. Waste Gas Temperature HBS	°C	361	360	400
II	**Flow Rates per Stove**				
15	Blast Furnace Gas	Nm³/h (wet)	21422	25697	27446
16	Coke Oven Gas	Nm³/h (wet)	2283	1043	807
17	Combustion Gas Total	Nm³/h (wet)	23705	26740	28253
18	Combustion Air	Nm³/h (wet)	25338	21887	21836
19	Waste Gas	Nm³/h (wet)	45763	45210	46533
III	**Flow Rates of Stove Plant**				
20	Blast Furnace Gas	Nm³/h (wet)	42844	51393	54892
21	Coke Oven Gas	Nm³/h (wet)	4566	2086	1614
22	Combustion Gas Total	Nm³/h (wet)	47410	53479	56506
23	Combustion Air	Nm³/h (wet)	50675	43775	43672
24	Waste Gas	Nm³/h (wet)	91525	90420	93066
IV	**Gas-/ Air Consumption Entire Plant**				
25	Blast Furnace Gas	Nm³/h (wet)	39274	47110	50318
26	Coke Oven Gas	Nm³/h (wet)	4185	1913	1479
27	Additional Blast Furnace Gas	Nm³/h (wet)	0	0	0
28	Combustion Gas Total	Nm³/h (wet)	43459	49023	51797
29	Combustion Air (Stoves Only)	Nm³/h (wet)	46452	40127	40033
30	Waste Gas (Stoves Only)	Nm³/h (wet)	83898	82885	85311
V	**Energy Consumption Entire Plant**				
31	Energy Requirement Hot Blast	GJ/h	154,5	154,5	154,5
32	Chemical Energy by Blast Furnace Gas	GJ/h	117,3	140,7	150,3
33	Chemical Energy by Coke Oven Gas	GJ/h	76,3	34,8	27,0
34	Chemical Energy by Additional Blast Furnace Ga	GJ/h	0,0	0,0	0,0
35	Chemical Energy Total	GJ/h	193,6	175,6	177,3
36	Energy Total	GJ/h	197,8	197,7	204,0
VI	**Plant Parameters**				
37	Efficiency Gross Chemical	%	79,81	87,99	87,15
38	Excess Air Rate	-	1,10	1,10	1,10
39	O_2 in Waste Gas	%	1,03	0,90	0,87
40	Flow Rate Adaption	-	1,09	1,09	1,09
41	Combustion Chamber Load	%	68	62	62

The energy consumption of the plant for the three cases are graphically illustrated in Figure 9.

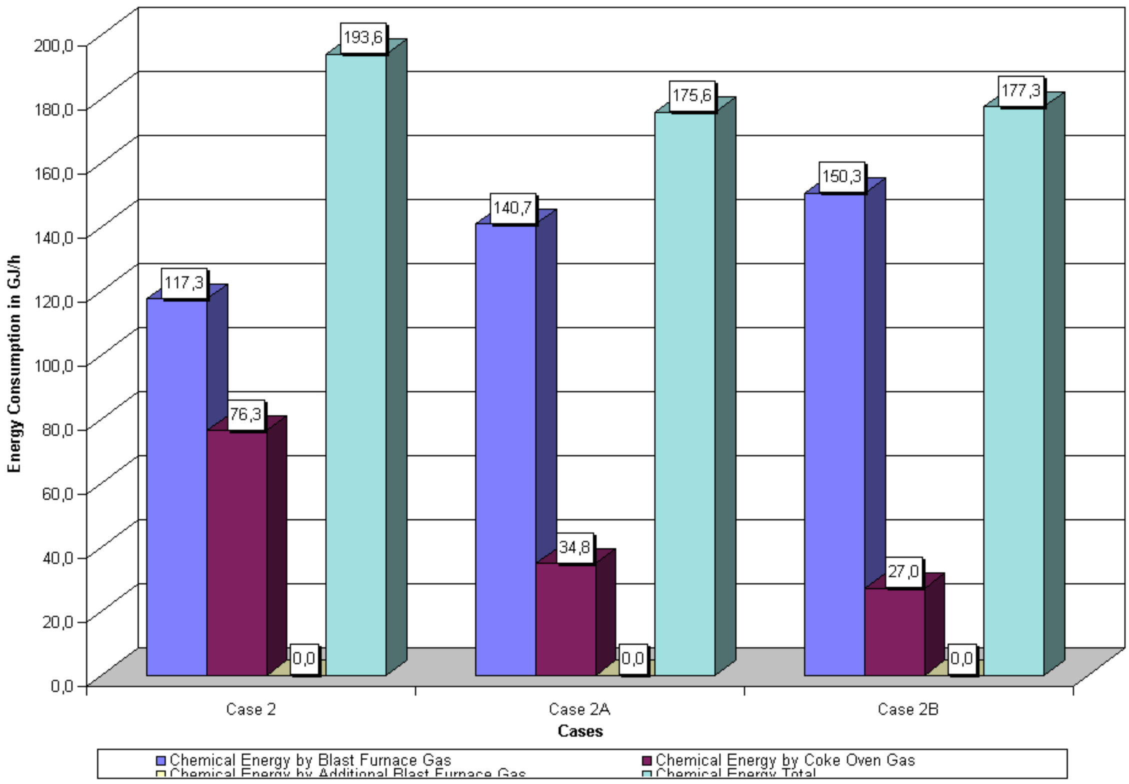

Figure 9 – Energy consumption entire plant.

The saving in energy consumption in comparison with the base case (Case 2) can be seen in Figure 10.

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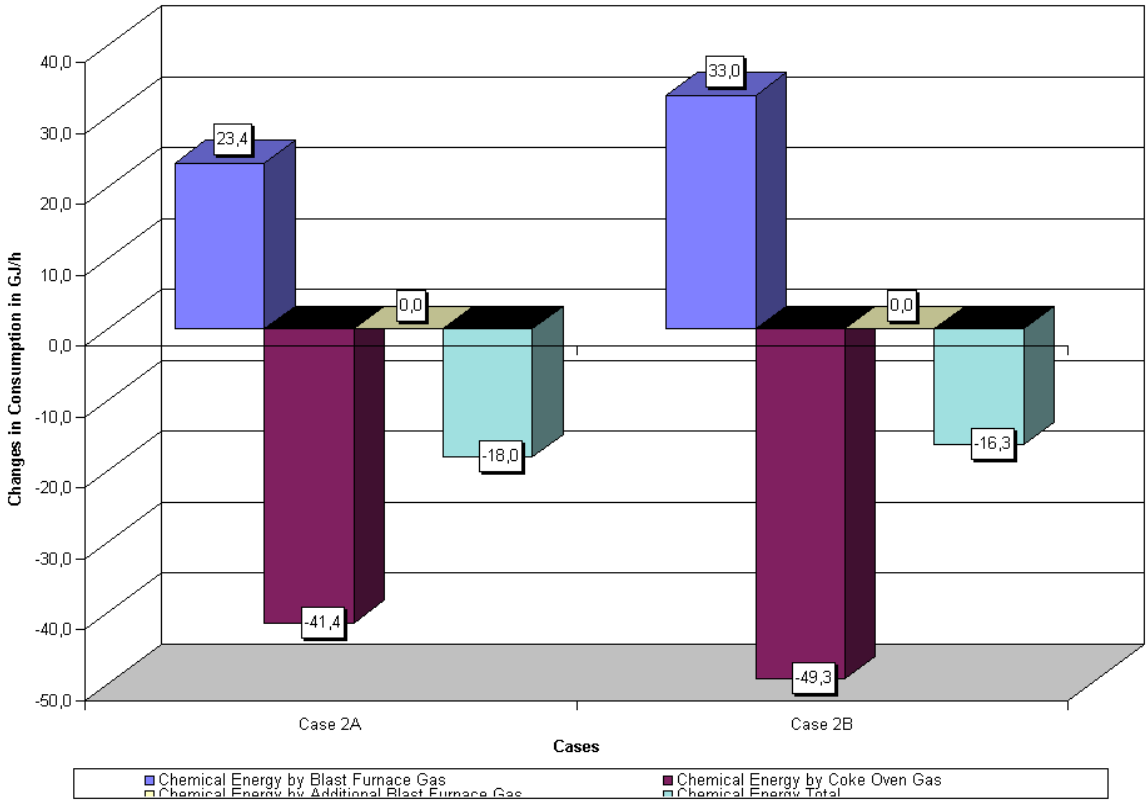

Figure 10 – Changes in energy consumption related to the basic case.

The saving in costs will depend on the price of the two gases, Blast Furnace Gas (BFG) and the high calorific gas (in this case Coke Oven Gas). As it can be seen in Figure 11, the higher the difference in price between the two gases, the higher the cost saving will be.

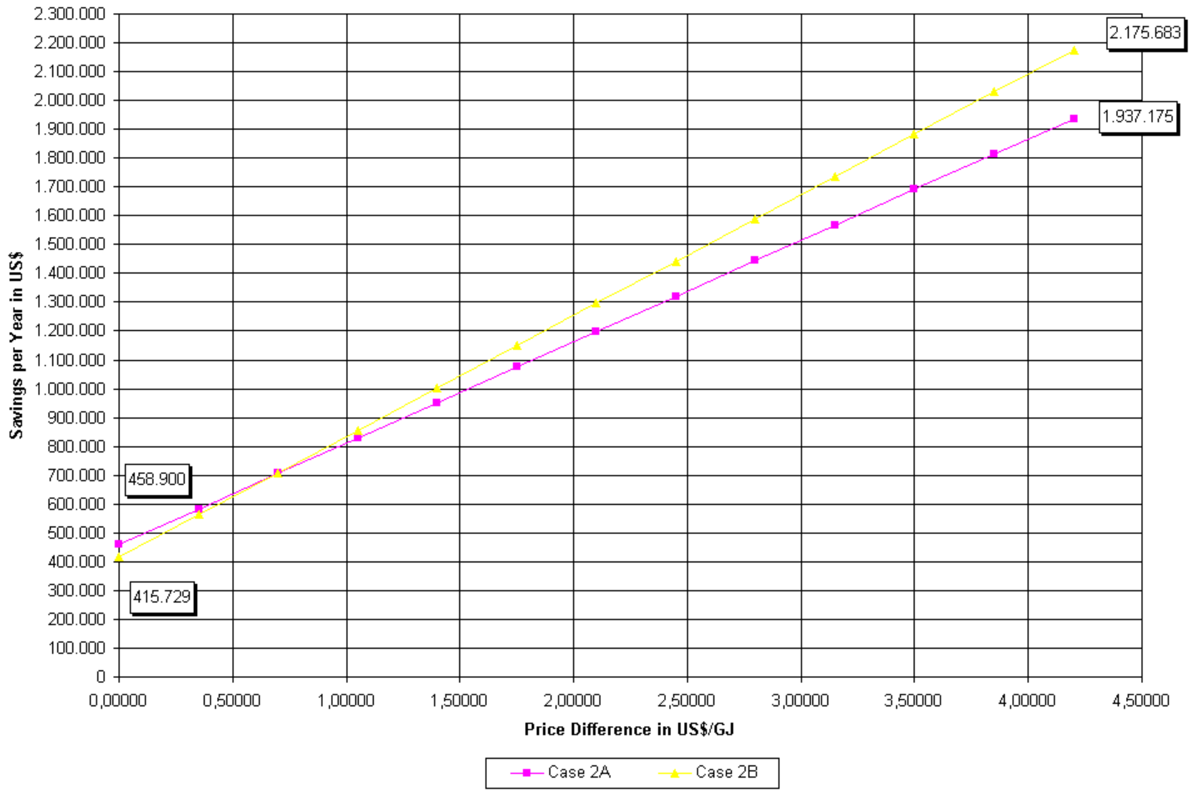

Figure 11 – Savings in energy costs at increasing price difference between blast furnace and high calorific gas.

PWR&E consider the situation in each plant individually, and through rigours discussion and consulting with the client, the most optimum system and configuration can be chosen.

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