Steam system optimization (SSO) Assessment

Name of the pilot:

Behran Oil Company (BOC)

SSO assessment final report

Revision: 06

Project Name: Reducing Greenhouse Gas Emissions through Improved Energy Efficiency in the Industrial Sector in Iran

Submitted to:

United National Industrial Development Organization

Project Management Unit (PMU)

Submitted by:

SSO Iran assessment team

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1- Introduction to the Behran Oil Company (BOC)

Steam system is one of the most important energy users in process plants. It can be divided into 4 sections: 1) Generation side, 2) Distribution and pipeline, 3) Steam consumers and 4) Condensate recovery and steam traps. Behran oil Co. is the leading lubricant manufacturing company in Iran with a dominant market share in terms of automotive and industrial lubricants, and also one of the top thirty worldwide lubricant manufacturing companies. Manufacturing & Marketing of more than 300,000 ton/yr of different 900 products including automotive oils, industrial oils, greases, petroleum waxes, process oils, engine coolants/antifreezes and furfural solvent. Behran oil Co. uses steam as a general heat source and feed stream in stripper columns. The main aim of this project is energy optimization based on steam system optimization tool (SSAT) that has taught in UNIDO training courses.

This report has written to identify the scope of the project, the required data and measurement plan as a feed for the steam system optimization tool (SSAT) and finally finding the conservation opportunities and their benefits for the company. Thus, the first step for finding energy conservation opportunities is studying the current condition of system and equipment.

2- Scope of work

The simplified schematic of the system that will be in the scope of work, is shown infigure 1.

The complete schematic of a system that will be in the scope of work, is on the attachment. The boiler BF-4410 & 4411 is under construction.However, because of SSAT limitations, the simple scheme of a system that shown in figure 1 was selected for simulation.

A team of experts who have been involved in this project are as below:

- UNIDO international consultant: Mr. Venkatesan Veerasamy
- UNIDO international consultant: Mr. Alexander Antomoshkin
- UNIDO technical expert of PMU: Mr. Mahdi Shakouri
- UNIDO national consultant: Mr. Naser Rezakhani
- BOC head of engineering and technical department: Ms. Raziyeh Mehrabi
- BOC head of process engineering department: Mr. Hossein Hajian
- BOC energy experts: Mr. Navid Abdoos & Mr. Iman Tirooni

This report has been prepared by Mr. Naser Rezakhani with the help of PMU and reviewed by international consultant.

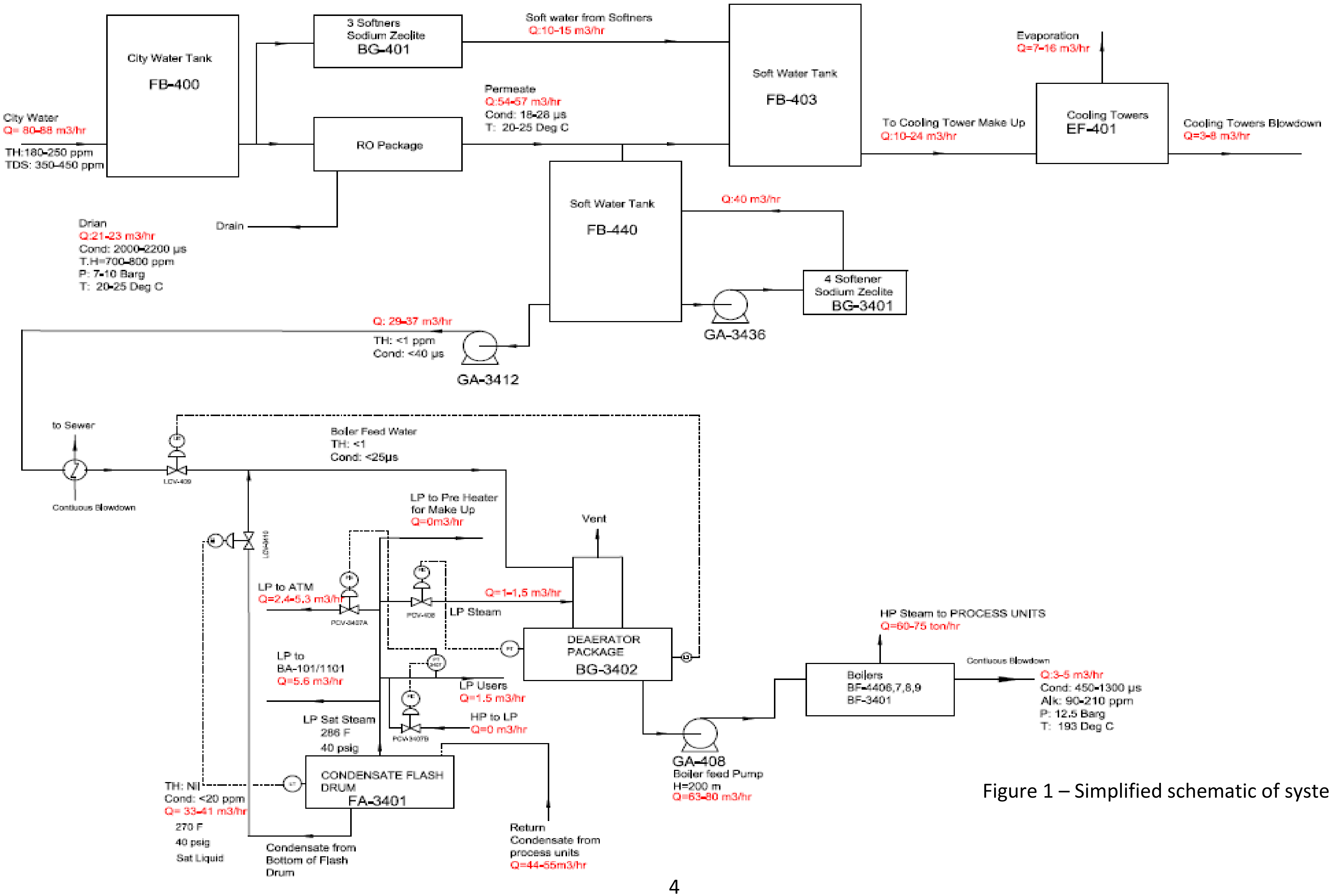


Figure 1 – Simplified schematic of system

3- Description of the steam system in the BOC

3-1 Generation

There are five steam boilers (3×32 ton/hr plus 2×14 ton/hr) to generate high-pressure steam (HPS) directly whereas low-pressure steam (LP) is produced in condensate flash drum (FA-3401). One deaerator (BG-4402) is used for HP production in five steam boilers. Some portion of LP steam is transferring to process furnaces to generate superheated steam (SHS). It means three states of steam are available in the production plant.

Two boilers with the capacity of 32 ton/hr manufactured in Mashinsazi arak Corporation. Another 32 ton/hr boiler manufactured in Garmagostar Corporation and two remaining boilers manufactured in Superactive Corporation. Make up water is preheated by blow down economizer. Inlet and outlet temperatures are not available around this economizer. The flow rate of boiler feed water (BFW) is being measured by water flow meter. Likewise, the fuel gas flow rate is available through online fuel gas counters. The electrical conductivity of blowdown is being measured regularly every 8 hours and electrical conductivity of BFW, condensate and makeup are measuring once a day. In our project, these data used for checking the boiler water condition. Continuous blowdown is being controlled by TDS controller and intermittent blow down is being controlled by a shut-off valve which opens every ten minutes. The operational pressure of deaerator (BG-4402) can be read from local pressure indicators.

The pressure of produced steam is measured with local pressure gauge and transmitter. But there isn’t any temperature indicator. So, the outlet pressure can be measured by Thermograph device. The portable gas analyzer has been provided by UNIDO. In addition, the efficiency of boilers calculated by described data using the direct method.

Process requirement is the main reason for installing a furnace. The waste flue gases used to produce superheat steam (SHS) in superheat steam boxes that located on top of the furnaces.

3-2 Distribution

There are 3 main pressure headers without let down station. Based on an agreement with BOC representative, the quality of insulation considered by using the thermo-gun device in MEK unit.

3-3 Consumption

Main consumption of steam in plant related to the process demand in 5 units including MEK, Utility, Furfural, Blending and Tank farm. Superheated steam is been used in stripper columns. There is no steam turbine or other steam drivers.

3-4 Condensate recovery

Collected returned condensate is being directed to flash drum. Some portion of the HP condensate is draining to the sewer as well as all LP condensate. Based on recent calculations, steam and condensate recovery are about 74% and 50-55%, respectively. The temperature of recovered condensate and all temperatures around the heat recovery exchanger (E4401) must be measured by thermograph device. The total number of steam traps is known and the last steam trap maintenance program was done more than 6 years ago, so this data used in SSAT model in the related specific section.

4- Data acquisition and the measurement plan

Tables 1 to 4 show the parameters which measured in the measuring step of the project.

Table 1- Specified measured data for the generation side

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
1	Pressure	psig	Deaerator	Deaerator	On-site pressure indicator	7
2	Temperature	°C	BFW	Before one of Boilers	On-site thermograph	95
3	Flow	m^3/hr	BFW	Boiler 5	On-site flow meter	16.53
4	Flow	m^3/hr	BFW	Boiler6	On-site flow meter	8.35
5	Flow	m^3/hr	BFW	Boiler 7	On-site flow meter	7.6
6	Flow	m^3/hr	BFW	Boiler 8	On-site flow meter	23.14
7	Flow	m^3/hr	BFW	Boiler 9	On-site flow meter	14.23
8	Flow	Nm^3/hr	Fuel Gas	Boiler 5	On-site flow meter	600
9	Flow	Nm^3/hr	Fuel Gas	Boiler 6	On-site flow meter	660
10	Flow	Nm^3/hr	Fuel Gas	Boiler 7	On-site flow meter	630
11	Flow	Nm^3/hr	Fuel Gas	Boiler 8	On-site flow meter	900
12	Flow	Nm^3/hr	Fuel Gas	Boiler 9	On-site flow meter	600
13	Temperature	°C	Steam	Boiler 5	On-site thermograph	196.7
14	Pressure	psig	Steam	Boiler 5	On-site pressure indicator	12.3
15	Temperature	°C	Steam	Boiler6	On-site thermograph	198.5
16	Pressure	psig	Steam	Boiler 6	On-site pressure indicator	12.5
17	Temperature	°C	Steam	Boiler 7	On-site thermograph	196.9
18	Pressure	psig	Steam	Boiler 7	On-site pressure indicator	12.5
19	Temperature	°C	Steam	Boiler 8	On-site thermograph	198.8

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
20	Pressure	psig	Steam	Boiler 8	On-site pressure indicator	12.5
21	Temperature	^{o}C	Steam	Boiler 9	On-site thermograph	192.7
22	Pressure	psig	Steam	Boiler 9	On-site pressure indicator	12.5
23	TDS	ppm	BFW	Same for all Boilers	From Lab.	36
24	TDS	ppm	Blowdown	Boiler 5	From Lab.	120
25	TDS	ppm	Blowdown	Boiler 6	From Lab.	1460
26	TDS	ppm	Blowdown	Boiler 7	From Lab.	360
27	TDS	ppm	Blowdown	Boiler 8	From Lab.	790
28	TDS	ppm	Blowdown	Boiler 9	From Lab.	590
29	Flow	m^3/hr	Steam	Boiler 5	On-site flow meter	14.66
30	Flow	m^3/hr	Steam	Boiler6	On-site flow meter	8.27
31	Flow	m^3/hr	Steam	Boiler 7	On-site flow meter	7.33
32	Flow	m^3/hr	Steam	Boiler 8	On-site flow meter	22.79
33	Flow	m^3/hr	Steam	Boiler 9	On-site flow meter	13.9
34	Flow	m^3/hr	Makeup water	All boilers	On-site flow meter	30
35	Temperature	^{o}C	Blowdown	Boiler 7,6	On-site thermograph	155
36	Temperature	^{o}C	Blowdown	Boiler 5,8,9	On-site thermograph	76

Table 2- Specified measured data for the distribution side

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
1	Pressure	psig	Steam	SHS Header	On-site pressure indicator	36
2	Temperature	^{O}F	Steam	SHS Header	On-site thermograph	520
3	Pressure	bag	Steam	HP Header	On-site pressure indicator	12.5
4	Temperature	^{O}C	Steam	HP Header	On-site thermograph	193
5	Pressure	bag	Steam	LP Header	On-site pressure indicator	2.7
6	Temperature	^{O}C	Steam	LP Header	On-site thermograph	315

Table 3-Specified measured data for the consumption side

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
1	Flow	Ibs/hr	Steam	Utility Unit	By Calculation	2860
2	Flow	Ibs/hr	Steam	MEK Unit	By Calculation	79335
3	Flow	Ibs/hr	Steam	Furfural Unit	By Calculation	20200
4	Flow	Ibs/hr	Steam	Tank Farm	By Calculation	12597
5	Flow	Ibs/hr	Steam	Blending Unit	By Calculation	22499

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
6	Flow	t/hr	Steam	Stripper Columns	On-site flow meter	1.5

Table 4-Specified measured data for the condensate recovery side

Row	Parameter	Unit	Stream/ Equipment	Location	Device	Value
1	Temperature	^{O}C	Condensate	Condensate header	On-site thermograph	135
2	Temperature	^{O}C	Makeup WATER	Inlet of E 4401	On-site thermograph	28.3
3	Temperature	^{O}C	Makeup WATER	The outlet of E 4401	On-site thermograph	34.8
4	Temperature	^{O}C	Boilers Inlet water	Boilers Inlet water	On-site thermograph	90
5	Temperature	^{O}C	water	Condensate Tank	On-site thermograph	123
6	Temperature	^{O}C	steam	Condensate Tank	On-site thermograph	144
7	TDS	ppm	Return Condensate	Condensate Header	From Lab.	1.25

5- Process simulation based on steam system assessment tool

5-1 The Assumption

Due to the fact that SSAT model has some limitations for simulation as well as availability of data for the project goals, we need to consider below assumptions for our developing model:

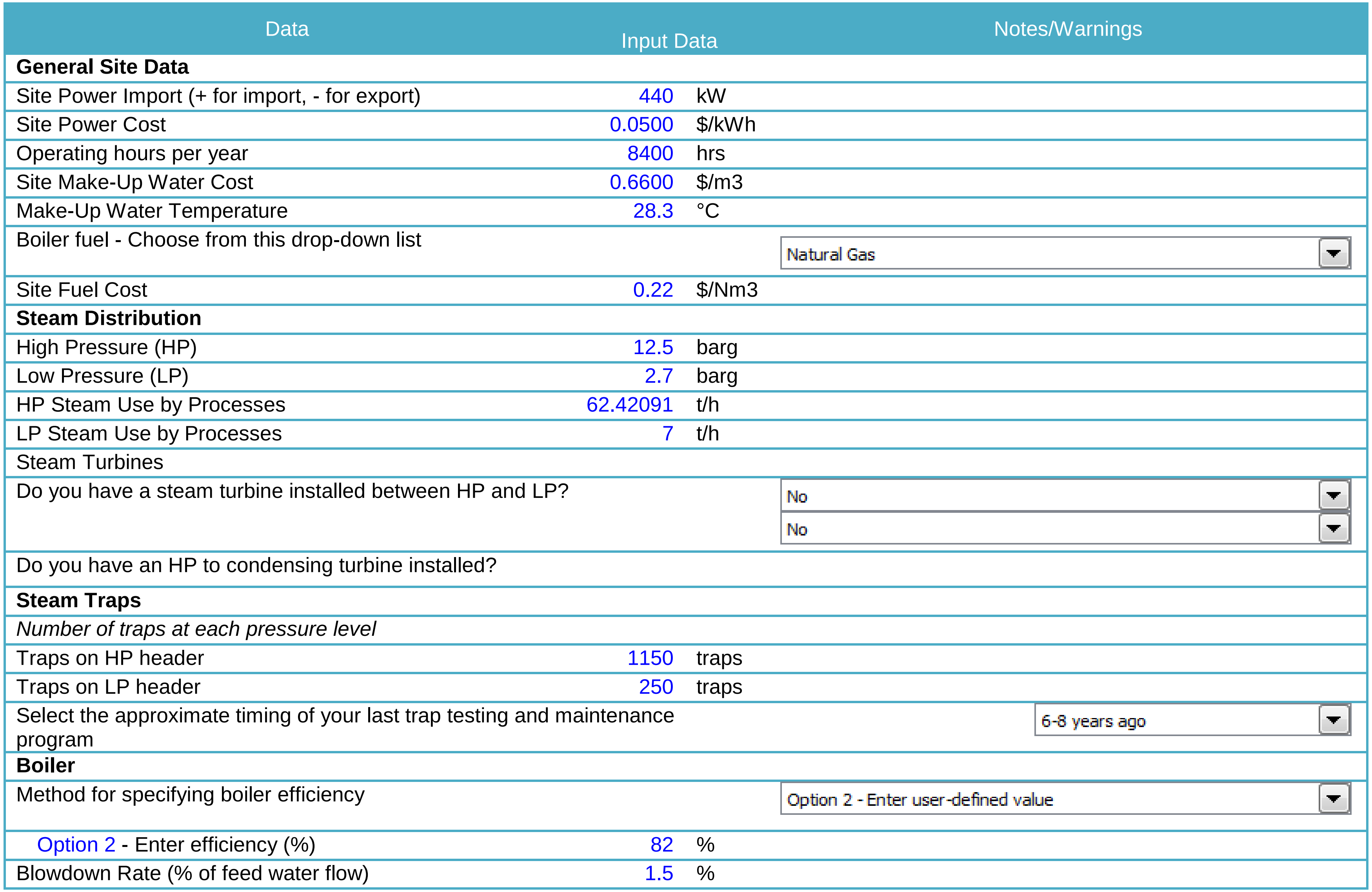
1. Since superheated steam produces in superheater economizer with same pressure level and different temperature, just 2 steam pressure headers considered in the scope of work. In addition, the amount of superheat steam is very low.
2. Because there isn't any device to measure the amount of process steam in consumption side, this data entered from engineering calculations based on the last investigation by Behran energy management team.

3. Although UNIDO experts and Behran staff tried to measure the insulation leaks, limitations in time and devices don’t let them make an accurate estimation of this item. Then the insulation leak considered as the SSAT default.

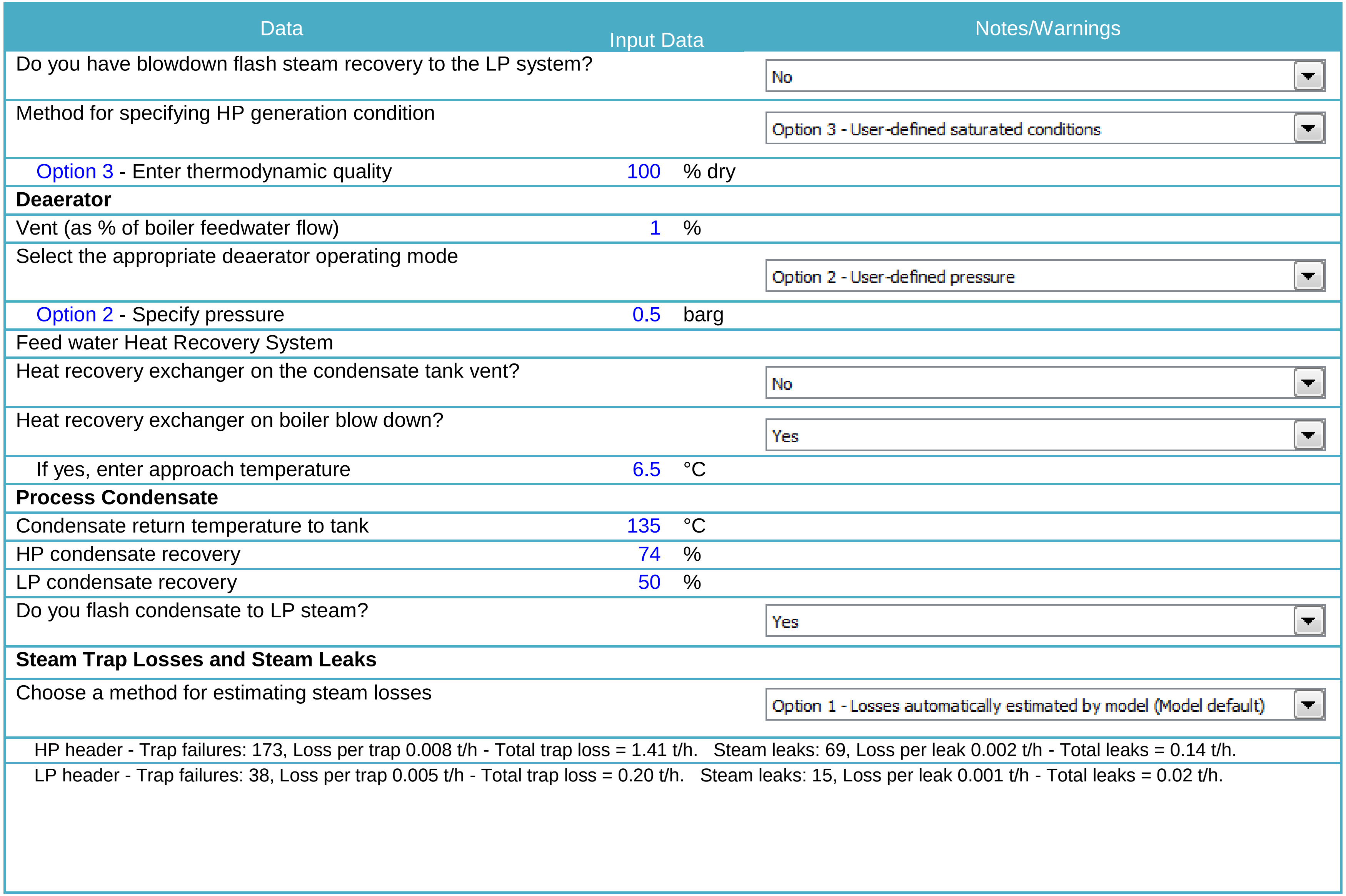
5-2 The Simulation

The SSAT tool is used to simulate the process in the scope of work. The simulation was done considering the gathered data which represented in table 1 to 4 and shown in the environment of SSAT tool in table 5. Some parts of entry data directly used from measurements and the remained parts have been calculated. In addition, the steam leak is calculated by the number of steam traps in each pressure level and the approximate timing of plant last trap testing and maintenance program.

Table 5– Behran Oil Refinery Case Description



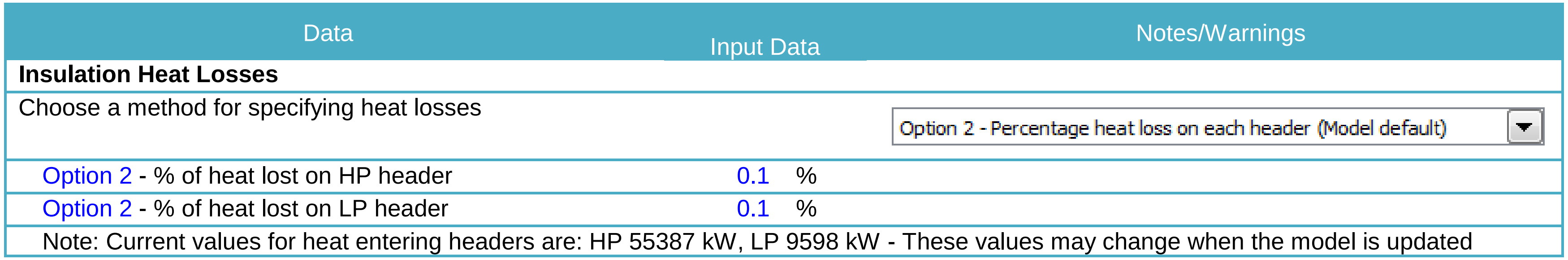
Data	Input Data		Notes/Warnings
General Site Data			
Site Power Import (+ for import, - for export)	440	kW	
Site Power Cost	0.0500	$/kWh	
Operating hours per year	8400	hrs	
Site Make-Up Water Cost	0.6600	$/m3	
Make-Up Water Temperature	28.3	°C	
Boiler fuel - Choose from this drop-down list			Natural Gas ▼
Site Fuel Cost	0.22	$/Nm3	
Steam Distribution			
High Pressure (HP)	12.5	barg	
Low Pressure (LP)	2.7	barg	
HP Steam Use by Processes	62.42091	t/h	
LP Steam Use by Processes	7	t/h	
Steam Turbines			
Do you have a steam turbine installed between HP and LP?			No ▼ No ▼
Do you have an HP to condensing turbine installed?			
Steam Traps			
Number of traps at each pressure level			
Traps on HP header	1150	traps	
Traps on LP header	250	traps	
Select the approximate timing of your last trap testing and maintenance program			6-8 years ago ▼
Boiler			
Method for specifying boiler efficiency			Option 2 - Enter user-defined value ▼
Option 2 - Enter efficiency (%)	82	%	
Blowdown Rate (% of feed water flow)	1.5	%	



Data	Input Data		Notes/Warnings
Do you have blowdown flash steam recovery to the LP system?			No
Method for specifying HP generation condition			Option 3 - User-defined saturated conditions
Option 3 - Enter thermodynamic quality	100	% dry	
Deaerator			
Vent (as % of boiler feedwater flow)	1	%	
Select the appropriate deaerator operating mode			Option 2 - User-defined pressure
Option 2 - Specify pressure	0.5	barg	
Feed water Heat Recovery System			
Heat recovery exchanger on the condensate tank vent?			No
Heat recovery exchanger on boiler blow down?			Yes
If yes, enter approach temperature	6.5	°C	
Process Condensate			
Condensate return temperature to tank	135	°C	
HP condensate recovery	74	%	
LP condensate recovery	50	%	
Do you flash condensate to LP steam?			Yes
Steam Trap Losses and Steam Leaks			
Choose a method for estimating steam losses			Option 1 - Losses automatically estimated by model (Model default)

HP header - Trap failures: 173, Loss per trap 0.008 t/h - Total trap loss = 1.41 t/h. Steam leaks: 69, Loss per leak 0.002 t/h - Total leaks = 0.14 t/h.

LP header - Trap failures: 38, Loss per trap 0.005 t/h - Total trap loss = 0.20 t/h. Steam leaks: 15, Loss per leak 0.001 t/h - Total leaks = 0.02 t/h.



Data	Input Data		Notes/Warnings
Insulation Heat Losses			
Choose a method for specifying heat losses			Option 2 - Percentage heat loss on each header (Model default) ▼
Option 2 - % of heat lost on HP header	0.1	%	
Option 2 - % of heat lost on LP header	0.1	%	
Note: Current values for heat entering headers are: HP 55387 kW, LP 9598 kW - These values may change when the model is updated			

6- Steam system conservation opportunities

As far as the SSO team of BOC have done site visits for identification of energy conservation opportunities (ECOs) as well as the simulation of BOC steam system in SSAT, potentials for improvement have been identified. In the below description, ECOs have been categorized in three sections including distribution, users and condensate recovery.

Steam generation system

- Gas analyzer measurements demonstrated the satisfactory efficiency of boilers except boiler #6, where excessive O_2 content was found – approximately 11%. This suggests good potential for improving boiler efficiency by 4-5%.
- Automatic TDS control is installed at a continuous blow down on all boilers and adjusted to open blow down valve at 2500 µS/cm. This value of dissolved solids concentration in the boiler water sounds too low for fire tube boilers, which are capable to accept much higher concentration of – up to 4000-4500 µS/cm. The increase of the TDS set level will lead to much lower blow down rate and, consequently, a noticeable increase in boiler efficiency.
- Orifice plate steam meters are installed on each boiler. Calibration is provided once a year, overall steam flow in winter and summer varies from 80 t/h to 50-60 t/h, which allows using orifice plates for steam metering. However, apparently there are no steam separators upstream meters, meaning the quality of steam reaching orifice (dryness and purity) is not good enough, causing rapid wear of the orifice and errors in measurements. Actually, SSO team uses feed water measurements for mass balance, due to not reliable readings of flow meters.

Steam distribution system

- Steam mains, carrying saturated steam, are not properly drained, causing erosion from entrained condensate and visible steam leaks. It's required to organize proper draining while transporting steam to the users, by means of installing drain pockets and steam traps for each 100m of pipe lengths.
- Some parts of steam mains lack insulation, but SSO team does not have thermovision camera, so they provided calculations based on measured pipework temperatures to identify poor insulation parts.
- Steam distribution manifolds and condensate manifolds for tracing are not insulated.
- Control valves, stop valves and ancillaries are not insulated.
- Steam manifolds are not bottom drained, which may cause water hammering, damages, and leaks from tracers. To avoid this bottom drain, stop valves at manifolds are constantly open and leaking steam.

- LP header is not properly drained.

Steam users and steam traps

- Some heat exchangers at MEK unit (new installation) are leaking, which means losing condensate to drain.
- There are 1100 steam traps installed, but the last traps survey was made 9 years ago. 400 traps were found failed in those days. Nowadays it should be at least twice more.
- There is no STMS in place, no traps tagging sustained.
- At blending unit wrong installation of process steam trap identified (upside down, blowing steam to condensate line).
- Poor design of PRV station at the steam input to the unit, when pressure reduction is made using a direct acting reducing valve in one step, with the pressure drop across the valve more than 10:1 (from 12,5 bar to 1 bar). Pneumatically actuated pressure reducing valve should be installed instead of direct-acting valve.
- Steam tracers at MEK and furfural units are designed not longer than 20-50 m, which goes in line with best practice.

Condensate return

- Initially, condensate system was designed to return 90% of condensate to the boiler house. Currently, it is 75% and less.
- Oil storage tanks are heated with HP steam. The initial design aimed to collect condensate locally and to pump it back to boiler house by pressure powered pump (old installation is still there, but not working). Condensate is returned to flash drum close to boilers using a pressurized condensate line.
- There are users, which are not returning condensate. One of the reasons – low process temperatures and pressures, the high back pressure in the condensate line. Therefore it is difficult to return condensate from distant exchangers, particularly which has relatively low process temperatures (and steam pressures).
- Returning pressurized condensate from HP steam users (including blowing steam from failed traps, open bypasses, high-temperature process) to common condensate flash drum causes excessive pressure in it. Actually, flash drum has a pressure of 2.8 bar, supplying LP steam to an LP header. The amount of LP steam is much bigger than required by the users. Part of LP steam goes to furnaces for superheating and using in stripping process, part – to deaerator. But a big amount of flash low-pressure steam is vented to atmosphere.

Identified opportunities for improvement

All opportunities have been discussed with the SSO team, priorities are seen as follows:
1. Increase condensate recovery rate.
Several steps should be made to achieve this target.

- Introduce proper STMS, to minimize blowing steam to condensate line through failed traps.
- Expand the condensate network, to be able to collect condensate from distant units and users. When doing this it makes sense to separate MEK, furfural and blending units' condensate lines, to collect condensate locally (having local condensate tanks instead of one common tank) and then pumping it to boiler house using electric or pressure powered pumps installations.
- Instead of venting excessive LP to the atmosphere it's worth thinking about using thermo compressors and supply midpressure steam (say 5-8 bar) to distant users, reducing usage of HP steam where possible.

2. Eliminate steam leaks.
It is not about just fixing the leak, but to remove the reason for it. Very often it is caused by low quality of steam (wet and dirty), poor drainage and poor traps performance (see the above). Quick replacement of failed traps is vitally important, so it might require changes in approach to ordering and supply.
3. Improve boiler efficiency.
4. Improve the steam distribution system.

SSAT model steam conservation projects and results

Projects which selected and defined on SSAT model are listed as below:

1. Reduce LP steam demand
2. Increase boiler efficiency
3. Decrease boiler blowdown rate
4. Increase HP condensate recovery
5. Increase LP condensate recovery
6. Steam trap losses maintenance program
7. Steam leaks maintenance program
8. Improve pipe work insulation

The result of steam system assessment tool shows these selected projects are capable to lead a considerable energy conservation in the BOC site (based on natural gas consumption) with the amount of 7.7% and total cost reduction will be around 8%. The more detail data can be found on table 6.

Table 6 - The result of implementing conservation opportunity

Cost Summary	Reduction	
Fuel Cost		7.7%
Make-Up Water Cost		41.3%
Total Cost		8%
CO2 Emissions	6513 t/yr	7.7%
NOx Emissions	13 t/yr	7.7%
Boiler Duty	4312 kW	7.7%
Fuel Consumption	386.7Nm3/h	7.7%
Boiler Steam Flow	4.6 t/h	6.5%

7- Conclusions and recommendations

After defining a measurement plan by national expert of the project, measurements were done by participation of PMU, national expert and internal team of BOC. Thereafter, a model for simulation of the BOC steam system developed by national expert. Then, PMU and international expert had a site visit in order to identify energy conservation opportunities (ECOs). Lastly, SSAT model revised in order to consider priorities identified ECOs. The result of steam system assessment tool (SSAT) shows selected projects are capable to lead a considerable energy conservation in the BOC site (based on natural gas consumption) with the amount of 7.7% and total cost reduction will be around 8%.

As the energy management system (EnMS) is in place within the company, it is recommended to put all the identified energy conservation opportunities of this program within the ECO list of EnMS. Thereafter, it is suggested that the energy team of the company work on prioritizing each ECO and develop an action plan for implementation. It's obvious that for getting the better result, the energy team shall present outputs of this program to the top manager of the plant, in order to get his commitment to support required investments if applicable.

Annex 1: Boiler Efficiency Calculation in Direct Method (Special case in the pilot for improvement)

Boiler efficiency (or steam generation efficiency) is defined as the ratio of the heat absorbed by feedwater to generate steam and the fuel input energy.

$\eta_{boiler} = m_{steam} (h_{steam} - h_{feedwater}) \times 100 / m_{fuel} \times HHV_{fuel}$

where h_{steam} and $h_{feedwater}$ are the enthalpies of steam and feedwater, respectively. This equation can be applied to a specific boiler or a complete boiler plant. It can be applied for an instantaneous snapshot or any defined time-period (daily, month, annual, etc.). This is known as the “Direct Method” for calculating boiler efficiency.

Boiler Efficiency Calculation (Indirect Method)

There are different kinds of losses in an operating boiler: Shell loss, Blowdown loss, Stack (Combustion and Temperature) loss, Fly and Bottom ash loss, Loss on Ignition (LOI), etc. Using an energy balance on the boiler, the boiler efficiency can be calculated as:

$\eta_{boiler} = 100 - \lambda_{shell} - \lambda_{blowdown} - \lambda_{stack} - \lambda_{miscellaneous}$

where λ_{shell} represents the Shell loss (%); $\lambda_{blowdown}$ represents the Blowdown loss (%); λ_{stack} represents the Stack loss (%); and $\lambda_{miscellaneous}$ represents the other losses (%). This is known as the “Indirect Method” of calculating boiler efficiency. It requires significantly more information from the operating boiler compared to the “Direct Method” of boiler efficiency calculation and is more time consuming than the “Direct Method”.

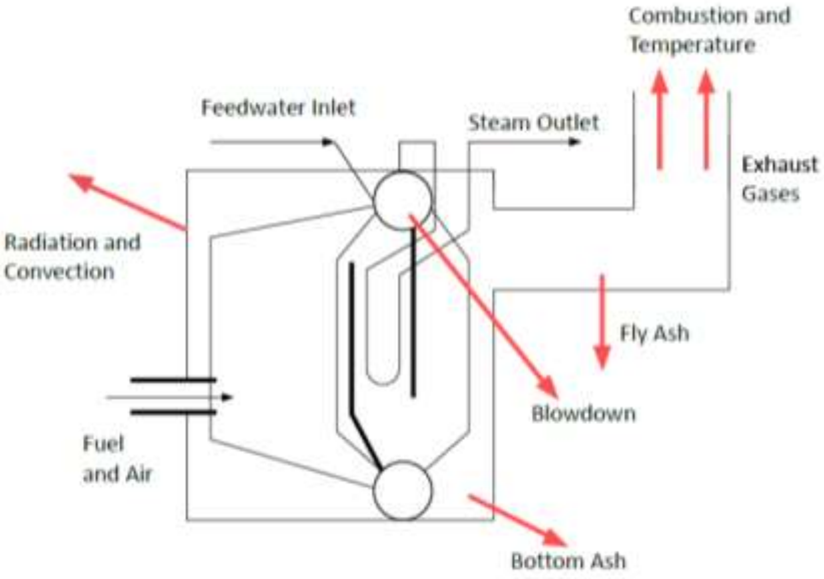


Figure 1 shows the amount of Behran oil boilers' stack loss (%) versus best practice stack loss (%). According to this figure, the amount of stack loss for the boiler number 6 is around 20 and it has the maximum gap with the best practise stack loss.

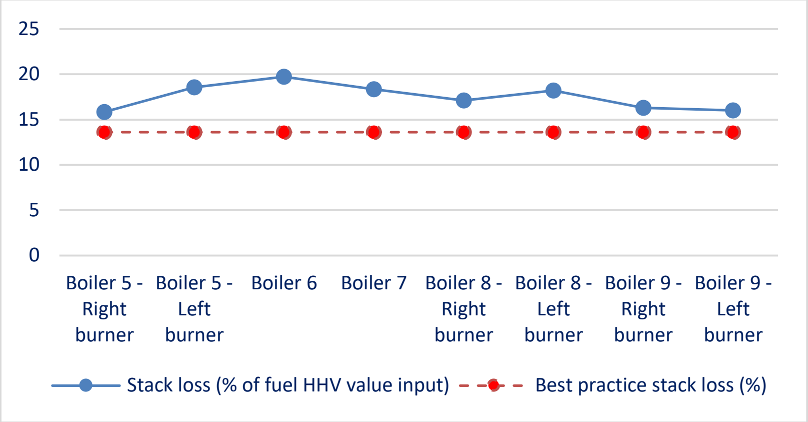


Figure 1 - Behran oil boilers' stack loss (%) vs. best practice stack loss (%)

Figure 2 represents the calculated amount for boiler efficiency of the Behran oil company using direct method. It is obvious that boiler number 8 has the best efficiency equal to 93.4% and the worse one is boiler number 9 with the efficiency of 85%.

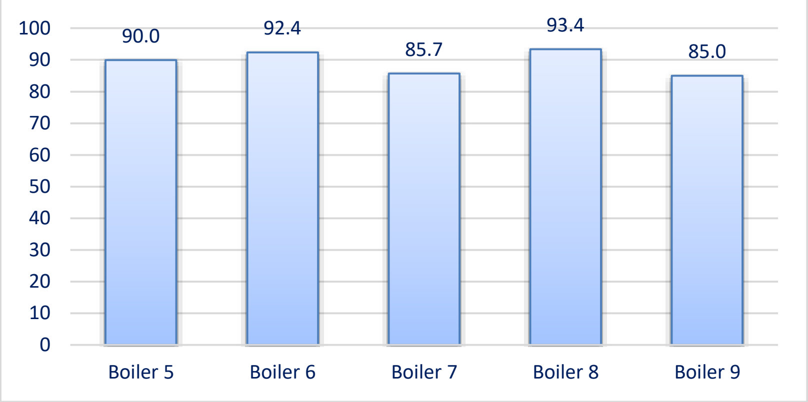


Figure 2 - Boiler Efficiency-Direct method (%)

Figure 3 represents the calculated amount for boiler efficiency of the Behran oil company using indirect method. It is obvious that boiler number 9 has the best efficiency equal to 81.1% and the worse one is boiler number 7 with the efficiency of 78%.

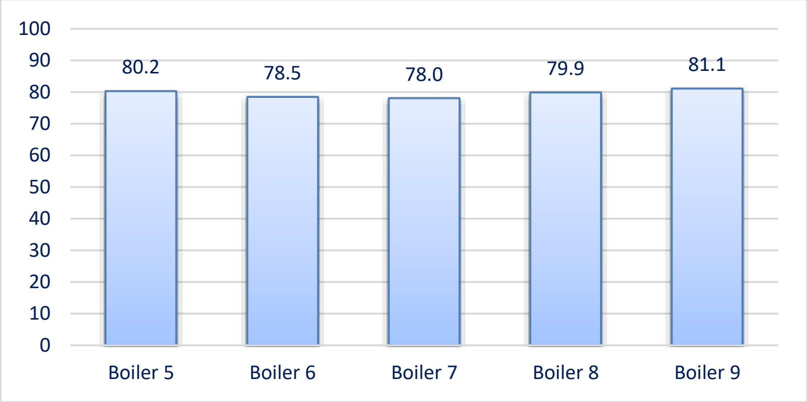


Figure 3 - Boiler Efficiency-Indirect method (%)

Figure 4 illustrates oxygen content percentage in flue gas for each boiler of Behran Oil Company. Optimum range for this parameter is between 2-3%. However, none of this pilot's boilers are between this ranges. The worst case happened for left burner of boiler number 5. Company shall take an action to adjust the inlet combustion air through damper of the air fan, especially for those cases in which the parameter is higher than 5.

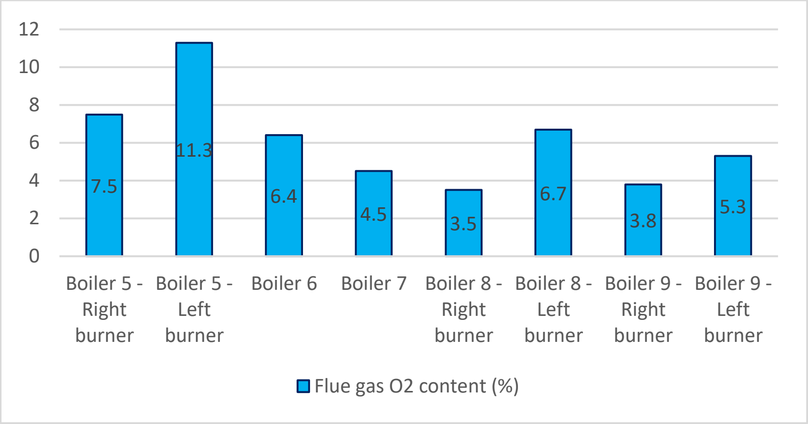


Figure 4 – Flue gas oxygen content in percentage

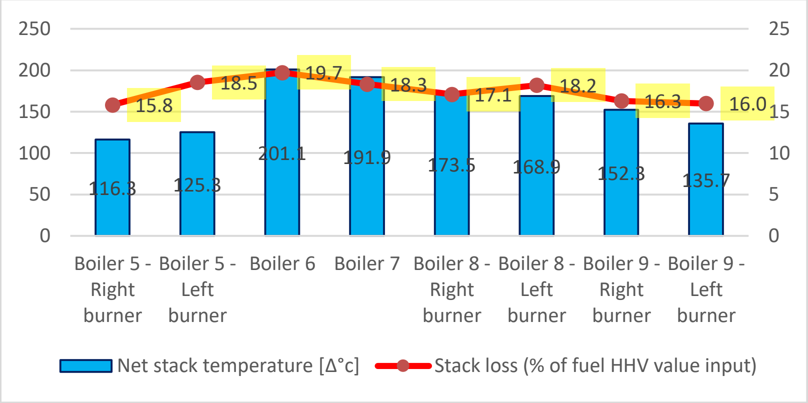


Figure 5 – Demonstration of net stack temperature and its effect on stack loss

Figure 5 shows the effect of net stack temperature on stack loss for each boiler of Behran Oil Company. According to these figures, the situation in boiler number 6 is the worst case and it needs to be considered by energy team.