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The Effect of Operating Condition on Low Pressure Steam (LPS) in Sugar Factory by Pinch Analysis

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Abstract
In the present work the sugar plant in Sragen, Central Java, Indonesia has ten evaporators that can be configured to five effect evaporators. The cane crushing rate in this plant still low by about 2500 TCD of 4000 TCD. The low capacity was suspected due to faulty operating condition on Low Pressure Steam (LPS). The effect faulty of LPS was not only low capacity of cane crushing rate but also high energy demand. Moreover, Steam on Cane reached 56% and the consequence leading to stop the production that affected to lower capacity production. Considering those problems, the optimization of energy demand, finding optimum operating condition of LPS, and choosing the best configuration of multiple effect evaporator (MEE) were performed by pinch analysis. In this paper, LPS at 0.4 kg/cm^2.G – 1.1 kg/cm^2.G were evaluated. The results show that the optimum operating condition of LPS was at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G. This optimum operating condition enhances the energy saving by about 30% compared to that of existing plant (0.4 kg/cm^2.G). The best performance value that can be achieved were Steam on Cane (SOC) by 43.50% and Steam Economy (SE) by 2.1.

Keywords : *Pinch analysis, Multiple Effect Evaporator, Optimization, Process Integration*

Abstrak
Pabrik gula berlokasi di Sragen, Jawa Tengah, Indonesia memiliki sepuluh unit evaporator yang dapat disusun dengan konfigurasi lima efek evaporator. Kapasitas giling pada pabrik ini masih rendah sekitar 2500 TCD hingga 4000 TCD. Kapasitas rendah tersebut diakibatkan oleh kondisi operasi Low Pressure Steam (LPS). Efek dari LPS tersebut tidak hanya menurunkan kapasitas giling tetapi meningkatkan kebutuhan energi pada pabrik. Terlebih, Steam on Cane mencapai 56% dan konsekuensi secara tidak langsung adalah berhenti produksi. Mempertimbangkan masalah-masalah tersebut pada paper ini author melakukan studi optimasi energi dengan kondisi operasi yang optimal, optimasi kondisi operasi yang optimum dan pemilihan konfigurasi multiple effect evaporator (MEE). Pada paper ini, LPS pada tekanan 0.4 kg/cm^2.G – 1.1 kg/cm^2.G dievaluasi. Hasil menunjukkan bahwa kondisi operasi LPS yang optimal berada pada rentang 0.9 kg/cm^2.G – 1.1 kg/cm^2.G. Pada kondisi operasi tersebut dapat meningkatkan energy saving sekitar 30% dibandingkan dengan existing plant (0.4 kg/cm^2.G). Nilai performa terbaik mendapatkan nilai Steam on Cane (SOC) sebesar 43.50% dan Steam Economy (SE) sebesar 2.1.

Kata kunci : Pinch analysis, Multiple Effect Evaporator, Optimization, Process Integration

1. Introduction

The sugar factory, which is the main focus of the present investigation, predominantly uses the Sulphitation Process to convert cane into sugar. The sulphitation process consists of MEE system as one of major section. This evaporation process obviously needs a large amount of heat. However MEE can be integrated in such a way that the generated steam from one effect can be bled to the other facilities (Higa et al. 2009). The energy efficiency of sugar plant can be enhanced by MEE configuration (Riadi, et al. 2021) and the configuration of steam bleeding from MEE (Somchart Chantasiriwan 2017). There are several research regarding optimization energy in sugar plant. (Umar, Ahmed, and Ahmed 2017) analyzed energy integration in Savannah sugar company with quadruple effect evaporator and proposed the best heat exchanger network by arranging steam bleeding from evaporator. Higa et al. (2009) has successfully developed thermal integration equations of various multiple effect evaporator configurations by defining equations that can be used as reference for thermal integration projects, the equations are also helpful for elaborating a systematic way to apply pinch analysis in sugar plant with an algorithm. Riadi et al. (2021) has successfully compared three configuration of MEE system (Triple Effect Evaporator, Quadruple Effect Evaporator and Quintuple Effect Evaporator) with existing plant. The result show quintuple effect evaporator was the best configuration with energy saving 8% compared to existing plant. Pina et al. (2015) simulated mass and heat balance in sugar-ethanol plant, simulate two cases production plan in order to minimize the utilities consumption, the result show that heat integration promoted a reduction in steam consumption of 35% approximately, while the reduction in water consumption was 24 and 13% in comparison to the conventional cases without heat integration. Petersen et al. (2015) compared three alternative processes to find the higher energy efficiency in sugar-bioethanol plant, the energy efficiency of each process scenario was maximized by pinch point analysis, the result show that heat integration was critical for the third process, whereby the energy efficiency was increased from 51,6% to 55,7%. Pinch analysis is a common method to optimize the energy system. It is generally used to evaluate the potentials for reducing the amount of external energy in the system (Linnhoff et al. 1982 and Kemp 2007). In the present work the sugar plant in Sragen, Central Java, Indonesia has ten evaporators that can be configured to five effect evaporators. Figure 1. shows an existing process flow diagram of sugar plant with a Sulphitation process

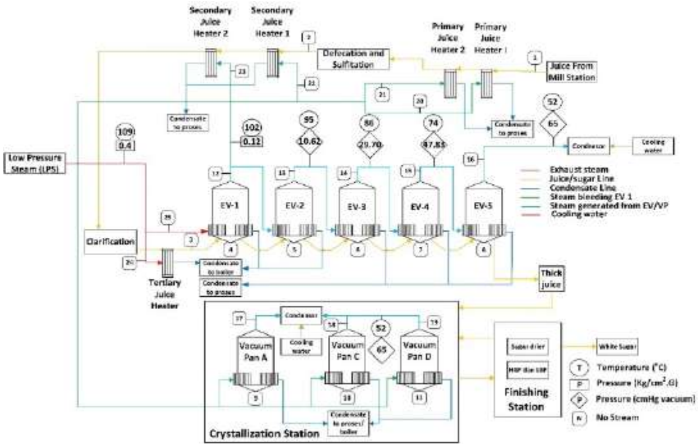

Figure 1. Process Flow Diagram existing cane sugar plant

The cane crushing rate in this plant still low by about 2500 Ton Cane per Day (TCD) from designed capacity of 4000 TCD. The low capacity was suspected due to faulty operating condition on LPS. The hypothesis that has been implemented is low pressure (by about 0.4 kg/cm^2.G) and low temperature (by about 109^{o}C) of heating steam (LPS) to evaporator. This condition makes the vapour pressure and temperature of the next effect lower. In addition, the configuration of vapour bleeding cannot reach optimum state. The effect of low pressure and low temperature of heating steam (LPS) to evaporator not only high energy demand in this plant but also other equipment operating condition fault. Moreover, Steam on Cane (SOC) reached 56% (including losses that caused by insulation issues and fault of operation), it means that every 100 tons of cane being crushed, it is taking 56 tons of steam produced from boiler (Singh et al. 1997). Beside that, inadequate operating condition of LPS will lead to a lower concentration of thick juice, resulting higher load in crystallization unit and leading to emergency stop the production. The other consequence is that the amount of evaporated water is not it should be, and hence, the plant requires more steam from the boiler. The boiler itself obviously has a certain capacity. If the required steam is higher than its limit, then the production rate will be low. Considering that problem, an appropriate method for optimization of process integration, finding optimum operating condition of LPS and choosing the best configuration of MEE are necessary.

There are 4 steps methodology in this research. The first step was to collect design and operational data. The collected data were 1) Operating condition: the juice/syrup concentration, temperature and pressure for each fluid (steam and juice), 2) Process configuration, 3) Heating surface evaporator. The second step was to calculate the energy requirement of existing plant at operating condition of LPS (P : 0.4 kg/cm^2.G and T : 109^{o}C) and to calculate the energy at various operating condition for LPS. Various operating condition of evaluated LPS were 0.4 kg/cm^2.G (at saturation condition) - 1.1 kg/cm^2.G (at saturation condition). The result of this step was a stream data extraction table for resource conservation to determine a system's source and sinks (Gadalla 2015). The third step was energy analysis by pinch method. After obtaining the stream extraction for making the temperature interval, the actual temperature in each stream was replaced by shifted temperature. Cold streams temperature are shifted above actual temperature. While hot streams temperature are shifted below actual temperature (Linnhoff et al. 1982 and Kemp 2007). Each interval will have a surplus or deficit energy that depends on amount of heat capacity flowrate of each interval (Riadi et al. 2021). After setting the temperature interval, the problem table, Grand Composite Curve (GCC), Composite Curve (CC) and Heat Exchanger Network (HEN) could be developed. From these steps, pinch point, maximum energy recovery (MER), minimum hot utility energy (QHmin), minimum cold utility energy (QCmin), and heat exchanger network (HEN) are evaluated. The fourth step was the evaluation of the optimized design by comparing the performance in each various operating condition with those of existing condition. The design was compared through these following performance parameter:

1. Steam on Cane (SOC)
   SOC is the ratio of the amount of steam produced by the boiler to the cane crushing rate (Singh et al. 1997).
2. Steam Economy (SE)
   SE is the comparison of amount of evaporated water to amount of external steam used to evaporate water (Chantasiriwan 2017).
3. Maximum Energy Recovery (MER)
4. Minimum hot utility energy (QHmin) and Minimum cold utility energy (QCmin)
5. Maximum capacity of cane crushing rate
   The maximum capacity of cane crushing rate is evaluated by comparing minimum heating surface required of MEE to installed heating surface in this plant.
   The determination of minimum heating surface of each evaporator (Hugot, 1986) has been formulated a correlation between heating surface and evaporation capacity of ith evaporator effect as shown in Eq. (1)
   $$Si = \frac{Vev_i}{C\Delta T_i} \quad (1)$$
   Where Si is the heating surface evaporator effect of ith, Vevi is the evaporation capacity evaporator effect of ith, C is 70pecific evaporation coefficient and ΔT is temperature drop of ith evaporator effect i.
6. Energy saving comparison
   Energy saving potential for new integration works can be calculated by Eq. (2) and Eq. (3) (Zhang et al. 2015).
   $$\delta hot = \frac{QH-QHmin}{QH} x100\% \quad (2)$$
   $$\delta cold = \frac{QC-QCmin}{QC} x100\% \quad (3)$$
   Where, QH is the existing configuration hot utility demand, kW; Qhmin is new integration works minimum hot utility required, kW; Qcmin is new integration works minimum cold utility required, kW.

2. Model Development Multiple Effect Evaporator

Mathematical models on evaporator effect i can be described by mass balance equation (Eq (4)) (Burke 2014).

$$mev_{i-1}\ x\ Bev_{i-1} = Vev_i + mev_i\ x\ Bev_i \quad (4)$$

Table 1. Distribution of pressure drop between effect

Effect	Pressure drop
1	$\frac{11}{50} x\Delta P$
2	$\frac{10.5}{50} x\Delta P$
3	$\frac{10}{50} x\Delta P$
4	$\frac{9.5}{50} x\Delta P$
5	$\frac{9}{50} x\Delta P$

Table 2. Constant data for MEE

Data	Value	Unit
Clear Juice flow	109.72	% cane
%brix clear juice	11.6	% brix
Pressure exhaust steam from steam turbine	2	Kg/cm^2.a
%brix thick juice	64	% brix

Where mevi-1 is flowrate of juice entering evaporator effect i, Bevi-1 is brix of juice entering evaporator effect i, Vevi is flowrate of produced vapor from evaporator effect ith, mevi is flowrate of juice leaving evaporator effect i, and Bevi is brix of juice leaving evaporator effect i. To determine the pressure of each evaporator, (Hugot, 1986) it has been formulated a correlation between input pressure and final pressure. Thus, operating condition of each evaporator can be developed. Table 1 shows distribution of pressure drop between effects. Due to the steam is in saturation condition, the pressure in each stage follows the saturation temperature. So that the produced energy at each evaporator is latent energy. To complete degree of freedom in MEE, constant data are obtained as shown in Table 2. Boiling point rise of the juice can occur due to brix concentration of the juice. The estimation of boiling poin rise of the juice can be calculated using Eq (5) (Hugot, 1986).

$$e = \frac{2B}{100-B} \tag{5}$$

Where e is boiling point rise (in oC) and B is concentration of the juice in %brix. The vapor and juice in ith effect evaporator are in equilibrium and the relation for the liquor and vapor temperature defined in terms of BPR is expressed as the Eq. (6) (Kumar et al. 2013).

$$Tli = Tvi + ei \tag{6}$$

Where Tli is temperature of juice, Tvi is temperature of vapour and ei is boiling point rise (BPR).

3. Model Development Juice Heater

The value of latent heat condensation of vapor bleeding is equal to the value of heat sensible of raising temperature of the juice in juice heater. The equation can be formulated as shown in Eq (7).

Table 3. Constant data for juice heater

Data	Value	Unit
Mixed juice flow rate	120.06	%cane
Sulphited juice flow rate	123	%cane
Clear juice flow rate	109.72	%cane
%brix mixed juice	12.67	%brix
%brix sulphited juice	12.37	%brix
%brix clear juice	11.6	%brix

$$Vev_j \ x \ hev_j \ = mJ_i \ x \ C_{pi} \ x \ (TJH_i - TJH_{i-1}) \qquad (7)$$

Where Cpi is average heat capacity of the juice between TJHi and TJHi-1. To complete degree of freedom at each juice heater, constant data are obtained as shown in Table 3.

4. Model Development Vacuum Pan

Crystallization process was carried out in three stages: Pan A crystallization to produce massecuite A with brix concentration of 95.22%, pan C crystallization to produce massecuite C with brix concentration of 98.26% and pan D crystallization to produce massecuite D with brix concentration of 99.2%. To complete the degree of freedom at each vacuum pan, constant data are obtained as shown in Table 4 for vacuum pan A, C, and D, respectively.To achieve brix concentration of each massecuite, steam is required for each vacuum pan as shown in Eq (8), mass balance in a single evaporation has been proposed by (Geankoplis, 1993).

Table 4. Constant data for vacuum pan A

Massecuite A		
Massecuite A feed	Brix consentration	Flow %cane
Condensate for washing massecuite A	0	1.77
Thick juice	64	Thick juice from last evaporator
A wash molasses	80.39	1.73
High remelt	78	0.1
Magma C	92.5	2.7
Magma D-2	93.6	0.19
Massecuite C		
Condensate for washing massecuite C	0	0.65
A molasses	85	3.82
Magma D-2	93.6	3.32
Massecuite D		
Condensate for washing massecuite D	0	0.87
A molasses	80.39	5
C molasses	84	4.6
D wash molasses	80.56	0.64

$$F_i h_{fi} + S_i \lambda_i = L_i h_{Li} + V_i H_{Vi} \qquad (8)$$

Where F is feed flow for massecuite i, hfi is feed enthalpy at spesific temperature, Si is vapor flow to boil the feed into massecuite, λi is latent energy of steam input, Li is massecuite flow, hLi is the enthalpy of massecuite i, Vi is evaporation capacity from vacuum pan i and Hvi is the enthalpy of juice vapor. To obtain enthalpy of juice vapor, Eq (9) was used for calculation.

$$H_{Vi} = HS_i + cp_{sh} BPR_i \qquad (9)$$

Where HSi is enthalpy of saturated vapor and cpsh is heat capacity of superheated vapor.

5. Stream Data Extraction

Calculation of mass and heat balance has been carried out for existing plant and various operating condition of LPS. The result of mass and heat balance are summarized in Table 5 - 12. So that the process data stream can be extracted and classified into two types based on heating and cooling demands.

Table 5. Process data stream for Low Pressure Steam (LPS) at 0.4 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	102.35	102.45	462219.38	46221.94
5	Water EV 2	Cold	95.51	95.61	140900.99	14090.10
6	Water EV 3	Cold	86.69	86.79	142356.79	14235.68
7	Water EV 4	Cold	75.03	75.13	144280.53	14428.05
8	Water EV 5	Cold	54.15	54.25	147608.08	14760.81
9	Water VP A	Cold	57.13	57.23	103996.56	10399.66
10	Water VP C	Cold	56.50	56.60	15864.57	1586.46
11	Water VP D	Cold	56.61	56.71	28954.55	2895.46
12	Steam EV1	Hot	102	101.90	462219.38	46221.94
13	Steam EV2	Hot	95	94.90	140900.99	14090.10
14	Steam EV3	Hot	86	85.90	142356.79	14235.68
15	Steam EV 4	Hot	74	73.90	144280.53	14428.05
16	Steam EV 5	Hot	52	51.90	147608.08	14760.81
17	Steam VPA	Hot	52	51.90	103996.56	10399.66
18	Steam VPC	Hot	52	51.90	15864.57	1586.46
19	Steam VPD	Hot	52	51.90	28954.55	2895.46

Table 6. Process data stream for Low Pressure Steam (LPS) at 0.5 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	105.36	105.46	472967.63	47296.76
5	Water EV 2	Cold	97.52	97.62	137441.81	13744.18
6	Water EV 3	Cold	88.70	88.80	138865.03	13886.50
7	Water EV 4	Cold	76.05	76.15	140898.19	14089.82
8	Water EV 5	Cold	54.16	54.26	144303.74	14430.37
9	Water VP A	Cold	57.13	57.23	103996.56	10399.66
10	Water VP C	Cold	56.50	56.60	15864.57	1586.46
11	Water VP D	Cold	56.61	56.71	28954.55	2895.46
12	Steam EV1	Hot	105	104.90	472967.63	47296.76
13	Steam EV2	Hot	97	96.90	137441.81	13744.18
14	Steam EV3	Hot	88	87.90	138865.03	13886.50
15	Steam EV 4	Hot	75	74.90	140898.19	14089.82
16	Steam EV 5	Hot	52	51.90	144303.74	14430.37
17	Steam VPA	Hot	52	51.90	103996.56	10399.66
18	Steam VPC	Hot	52	51.90	15864.57	1586.46
19	Steam VPD	Hot	52	51.90	28954.55	2895.46

Table 7. Process data stream for Low Pressure Steam (LPS) at 0.6 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.58	11729.23
2	Sulphited Juice	Cold	75	105	240.80	7223.98
3	Clear Juice	Cold	95	105	215.87	2158.67
4	Water EV 1	Cold	106.36	106.46	476570.94	47657.09
5	Water EV 2	Cold	98.53	98.63	136243.43	13624.34
6	Water EV 3	Cold	89.70	89.80	137630.58	13763.06
7	Water EV 4	Cold	77.06	77.16	139673.48	13967.35
8	Water EV 5	Cold	54.17	54.27	143204.41	14320.44
9	Water VP A	Cold	57.13	57.23	103995.52	10399.55
10	Water VP C	Cold	56.50	56.60	15864.42	1586.44
11	Water VP D	Cold	56.61	56.71	28954.26	2895.43
12	Steam EV1	Hot	106	105.90	476570.94	47657.09
13	Steam EV2	Hot	98	97.90	136243.43	13624.34
14	Steam EV3	Hot	89	88.90	137630.58	13763.06
15	Steam EV 4	Hot	76	75.90	139673.48	13967.35
16	Steam EV 5	Hot	52	51.90	143204.41	14320.44
17	Steam VPA	Hot	52	51.90	103995.52	10399.55
18	Steam VPC	Hot	52	51.90	15864.42	1586.44
19	Steam VPD	Hot	52	51.90	28954.26	2895.43

Table 8. Process data stream for Low Pressure Steam (LPS) at 0.7 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	108.36	108.46	483753.87	48375.39
5	Water EV 2	Cold	100.53	100.63	133812.56	13381.26
6	Water EV 3	Cold	90.71	90.81	135352.07	13535.21
7	Water EV 4	Cold	78.07	78.17	137363.35	13736.34
8	Water EV 5	Cold	54.18	54.28	140988.63	14098.86
9	Water VP A	Cold	57.13	57.23	103996.56	10399.66
10	Water VP C	Cold	56.50	56.60	15864.57	1586.46
11	Water VP D	Cold	56.61	56.71	28954.55	2895.46
12	Steam EV1	Hot	108	107.90	483753.87	48375.39
13	Steam EV2	Hot	100	99.90	133812.56	13381.26
14	Steam EV3	Hot	90	89.90	135352.07	13535.21
15	Steam EV 4	Hot	77	76.90	137363.35	13736.34
16	Steam EV 5	Hot	52	51.90	140988.63	14098.86
17	Steam VPA	Hot	52	51.90	103996.56	10399.66
18	Steam VPC	Hot	52	51.90	15864.57	1586.46
19	Steam VPD	Hot	52	51.90	28954.55	2895.46

Table 9. Process data stream for Low Pressure Steam (LPS) at 0.8 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	109.36	109.46	487323.96	48732.40
5	Water EV 2	Cold	102.54	102.64	132281.75	13228.17
6	Water EV 3	Cold	92.22	92.32	134006.09	13400.61
7	Water EV 4	Cold	79.07	79.17	136124.57	13612.46
8	Water EV 5	Cold	54.18	54.28	139868.86	13986.89
9	Water VP A	Cold	57.13	57.23	103996.56	10399.66
10	Water VP C	Cold	56.50	56.60	15864.57	1586.46
11	Water VP D	Cold	56.61	56.71	28954.55	2895.46
12	Steam EV1	Hot	109	108.90	487323.96	48732.40
13	Steam EV2	Hot	102	101.90	132281.75	13228.17
14	Steam EV3	Hot	91.5	91.40	134006.09	13400.61
15	Steam EV 4	Hot	78	77.90	136124.57	13612.46
16	Steam EV 5	Hot	52	51.90	139868.86	13986.89
17	Steam VPA	Hot	52	51.90	103996.56	10399.66
18	Steam VPC	Hot	52	51.90	15864.57	1586.46
19	Steam VPD	Hot	52	51.90	28954.55	2895.46

Table 10. Process data stream for Low Pressure Steam (LPS) at 0.9 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (°C)	Temperature Actual out (°C)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	111.31	111.41	440590.99	44059.10
5	Water EV 2	Cold	103.55	103.65	226033.03	22603.30
6	Water EV 3	Cold	93.41	93.51	118088.37	11808.84
7	Water EV 4	Cold	79.94	80.04	119925.09	11992.51
8	Water EV 5	Cold	54.26	54.36	123164.31	12316.43
9	Water VP A	Cold	57.13	57.23	103904.98	10390.50
10	Water VP C	Cold	56.50	56.60	15850.60	1585.06
11	Water VP D	Cold	56.61	56.71	28929.05	2892.91
12	Steam EV1	Hot	110.96	110.86	440590.99	44059.10
13	Steam EV2	Hot	103	102.90	226033.03	22603.30
14	Steam EV3	Hot	92.624	92.52	118088.37	11808.84
15	Steam EV 4	Hot	78.77	78.67	119925.09	11992.51
16	Steam EV 5	Hot	52	51.90	123164.31	12316.43
17	Steam VPA	Hot	52	51.90	103904.98	10390.50
18	Steam VPC	Hot	52	51.90	15850.60	1585.06
19	Steam VPD	Hot	52	51.90	28929.05	2892.91

Table 11. Process data stream for Low Pressure Steam (LPS) at 1.0 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (ºC)	Temperature Actual out (ºC)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	113.35	113.45	439861.01	43986.10
5	Water EV 2	Cold	105.55	105.65	225337.34	22533.73
6	Water EV 3	Cold	94.79	94.89	117516.76	11751.68
7	Water EV 4	Cold	81.17	81.27	119379.01	11937.90
8	Water EV 5	Cold	54.27	54.37	122843.67	12284.37
9	Water VP A	Cold	57.13	57.23	103904.98	10390.50
10	Water VP C	Cold	56.50	56.60	15850.60	1585.06
11	Water VP D	Cold	56.61	56.71	28929.05	2892.91
12	Steam EV1	Hot	113	112.90	439861.01	43986.10
13	Steam EV2	Hot	105	104.90	225337.34	22533.73
14	Steam EV3	Hot	94	93.90	117516.76	11751.68
15	Steam EV 4	Hot	80	79.90	119379.01	11937.90
16	Steam EV 5	Hot	52	51.90	122843.67	12284.37
17	Steam VPA	Hot	52	51.90	103904.98	10390.50
18	Steam VPC	Hot	52	51.90	15850.60	1585.06
19	Steam VPD	Hot	52	51.90	28929.05	2892.91

Table 12. Process data stream for Low Pressure Steam (LPS) at 1.1 kg/cm^2.G

Stream	Name	Type	Temperature Actual in (ºC)	Temperature Actual out (ºC)	Heat capacity flow rate (kW/K)	Heat flow (kW)
1	Raw Juice	Cold	30	80	234.59	11729.35
2	Sulphited Juice	Cold	75	105	240.80	7224.06
3	Clear Juice	Cold	95	105	215.87	2158.69
4	Water EV 1	Cold	114.36	114.46	439795.00	43979.50
5	Water EV 2	Cold	106.18	106.28	225367.85	22536.79
6	Water EV 3	Cold	96.01	96.11	117432.53	11743.25
7	Water EV 4	Cold	82.00	82.10	119346.79	11934.68
8	Water EV 5	Cold	54.27	54.37	122846.17	12284.62
9	Water VP A	Cold	57.13	57.23	103904.98	10390.50
10	Water VP C	Cold	56.50	56.60	15850.60	1585.06
11	Water VP D	Cold	56.61	56.71	28929.05	2892.91
12	Steam EV1	Hot	114.01	113.91	439795.00	43979.50
13	Steam EV2	Hot	105.63	105.53	225367.85	22536.79
14	Steam EV3	Hot	95.22	95.12	117432.53	11743.25
15	Steam EV 4	Hot	80.83	80.73	119346.79	11934.68
16	Steam EV 5	Hot	52	51.90	122846.17	12284.62
17	Steam VPA	Hot	52	51.90	103904.98	10390.50
18	Steam VPC	Hot	52	51.90	15850.60	1585.06
19	Steam VPD	Hot	52	51.90	28929.05	2892.91

In process of evaporation, water is evaporated by steam to reach concentrated juice. In evaporation and condensation process temperature of steam or liquid doesn't change. For the convenient of calculation, 0.1ºC temperature rise for cold stream and temperature decrease for hot stream was assumed (Zhang et al. 2015). Then, heat capacity was multiplied by 10 for evaporation or condensation stream.

6. Case Study

The present study focuses on a typical sugar cane manufacture with processing capacity of 4000 TCD. For calculation of hot and cold utility target, a minimum temperature difference of 6ºC was selected to limit the heat transfer based on trial and operation. The temperature interval was set after acquiring stream data extraction. The actual temperature in each stream was replaced by shifted temperature. Each interval has a surplus or deficit of energy that depends on amount of heat capacity flowrate of each interval.

Based on pinch analysis results, the optimization and retrofitting of the heat exchanger networks for each configuration have been performed. Having used graphical representation of the process via simple diagram as GCC, the maximum energy transfer from hot streams to cold stream is maximized. Therefore, minimum utility requirements can be determined from grand composite curves which are based on specific ΔTmin between the hot and old streams (see Figure 2) and the GCC serves better to implying the interface between process and utility system (Valiani et al.2016). It can be seen in Figure 2, when the LPS condition was at the range of 0.4 kg/cm^2.G – 0.8 kg/cm^2.G, the above actual pinch temperature for cold stream requires heat supply from external hot utilities. Cold streams that need to be heated are evaporator effect 1, sulphited juice and clear juice up to temperature target based on process data stream. While LPS at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G five streams below pinch point temperature needs to be cooled. Hot and cold stream that need to be cooled are raw juice, evaporator last effect, vacuum pan A, vacuum pan C and vacuum pan D based on process data stream. Based on the pinch analysis results, the best configuration and optimum operating condition of LPS was at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G. The calculation result of performance parameters evaluation for all operating conditions of LPS is presented in Figure 3. All the parameters of performance value are in the best condition at the LPS of 0.9 – 1.1 kg/cm^2.G this operating condition can produce vapour bleeding of evaporator effect 1 and evaporator effect 2 at higher pressure and temperature, so that this operating condition can accommodate the demands of juice heater to reach target temperature from vapour bleeding. In addition, vapour bleeding from the last effect evaporator can be used to heat primary juice heater as shown in Figure 4. This operating condition not only results higher MER and Steam Economy (SE) but also results on lower SOC, minimum hot utility energy and minimum cold utility energy. Figure 3 shows SOC parameters and hot utility energy of existing configuration was lower than those of new integration works (optimized configuration) for LPS at 0.4 kg/cm^2.G.

It could be due to the existing plant forced the vapour bleeding from 1st effect evaporator to heat secondary juice heater (JH II) where the temperature of vapour bleeding from 1st effect evaporator was lower than temperature target of secondary juice heater (JH II). Moreover, the effect of this condition was that the juice can not be flashed properly resulting juice with higher turbidity. The bottleneck caused by low LPS is shown in Figure 5 that heating surface required is larger than installed heating surface at ranged LPS 0.4 – 0.8 kg/cm^2.G. LPS that suitable with installed heating surface ranged at 0.9 – 1.1 kg/cm^2.G. Furhter study is shown in Figure 6, the comparison of installed heating surface with required heating surface for LPS at 0.4 kg/cm^2.G – 0.7 kg/cm^2.G after adjusting the cane crushing rate. For LPS condition at 0.4 kg/cm^2.G, it can afford up to 2695.50 TCD, 0.5 kg/cm^2.G can afford up to 3048.64 TCD, 0.6 kg/cm^2.G can afford up to 3388.88 TCD and 0.7 kg/cm^2.G can afford up to 3773.68 TCD. The effect of low pressure level of LPS is not only on higher energy demand but also lower cane crushing rate. The LPS at 0.4 kg/cm^2.G – 0.7 kg/cm^2.G produces vapour bleeding only from evaporator 1 where this operating condition can accommodate the demands of juice heater to increase the temperature into targeted level partially. So that, evaporator effect 1 has greater capacity than other effects. It causes the evaporator effect 2 to the last effect have the same evaporation capacity to be taken. The installed evaporator effect 4 and evaporator effect 5 have the lower heating surface, but the evaporation capacity is too great to be taken and resulting debottleneck in cane crushing rate. Based on the pinch analysis results, the optimization and the retrofitting of the heat exchanger networks have been sucessfully performed as shown in Figure 4. The energy distribution scheme with LPS conditions at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G based on this optimization study is as follow 1) Vapour bleeding of evaporator effect 2 can be used to heat primary juice heater 2 (pinch point at 46ºC – 80ºC) and secondary juice heater 1 (75ºC – 90ºC), 2) Vapour bleeding of evaporator effect 1 can be used to heat secondary juice heater 2 (90ºC – 105ºC), vacuum pan A, C and D, and tertiary juice heater (95ºC – 105ºC), 3)Vapour bleeding of evaporator effect 5 can be utilized to heat primary juice heater 1 (30ºC to pinch point at 46ºC), 4) Hot external utility was only supplied from LPS to evaporator effect 1, and 5) Cold external utility was provided to withdraw heat from condenser vacuum pan A, C and D also condenser of last effect evaporator after heating primary juice heater 1. It can be seen in Figure 3 that according to the pinch analysis results, the maximum energy saving potential that can be acquired was about 30% with LPS at 0.9 – 1.1 kg/cm^2.G The hot and cold utility demands in the new integrated configuration were significantly reduced from the existing plant condition.

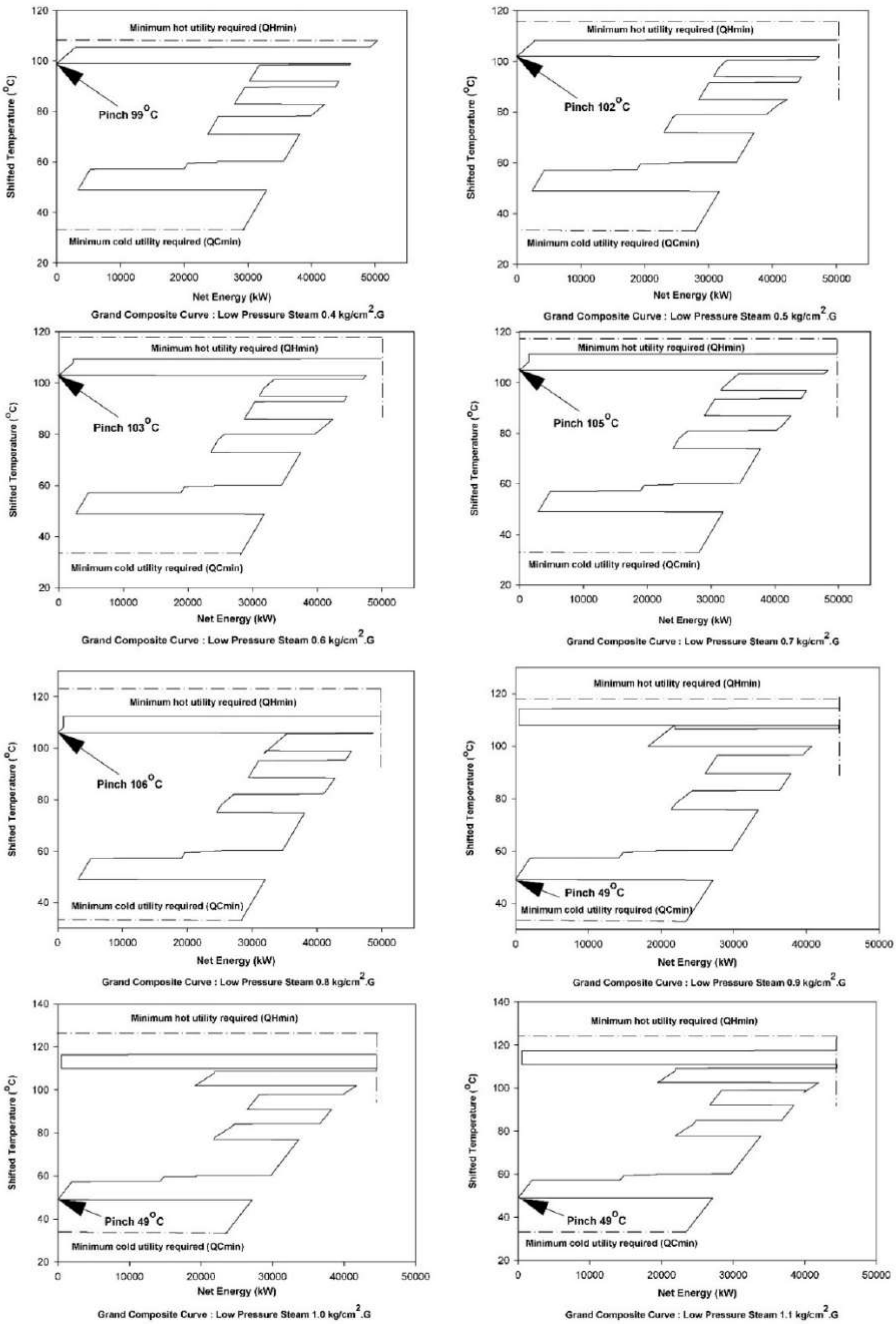

Figure 2. Grand Composite Curve (GCC) at various operating condition of Low Pressure Steam (LPS)

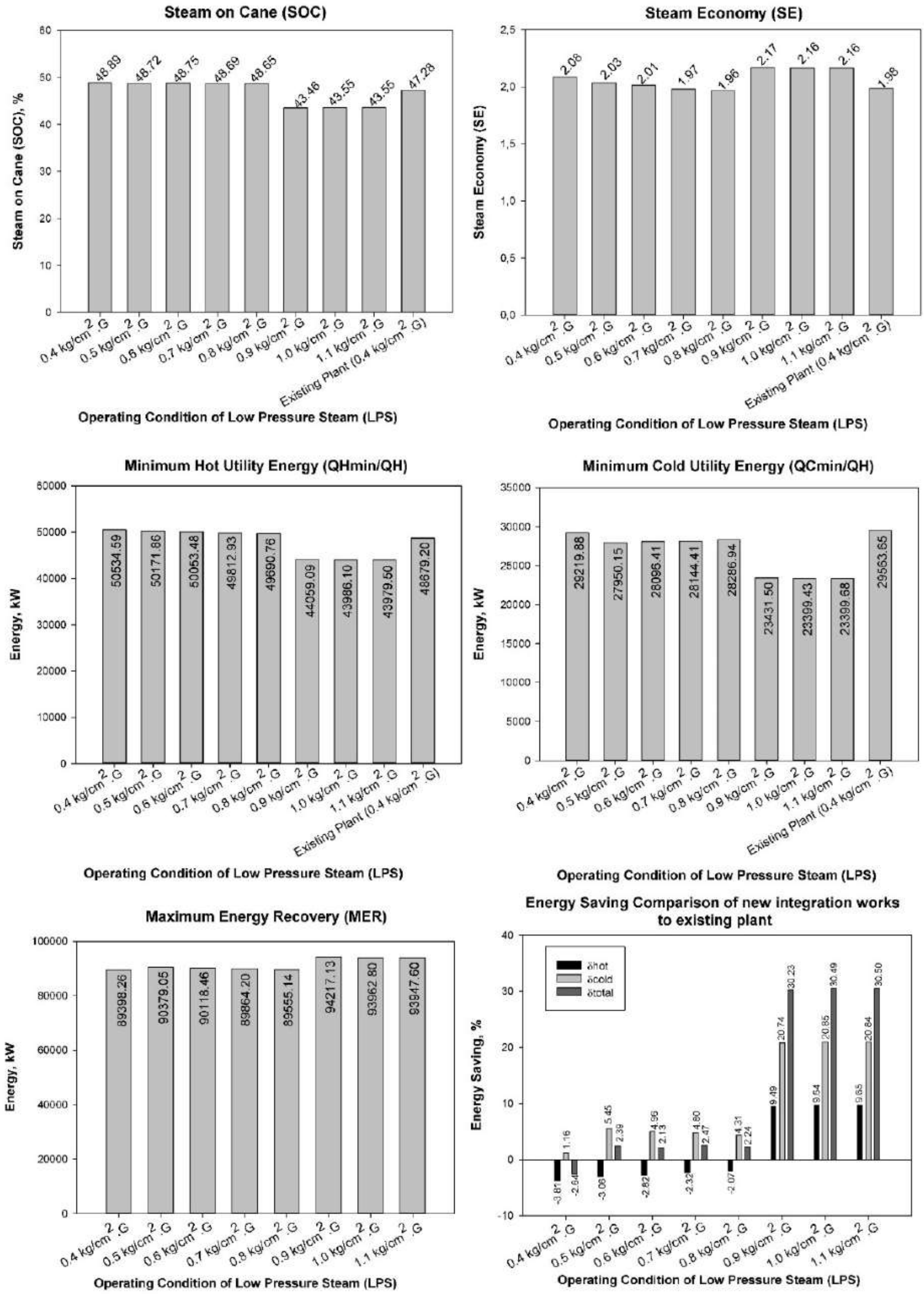

Figure 3. Performance parameters at various operating condition of Low Pressure Steam (LPS)

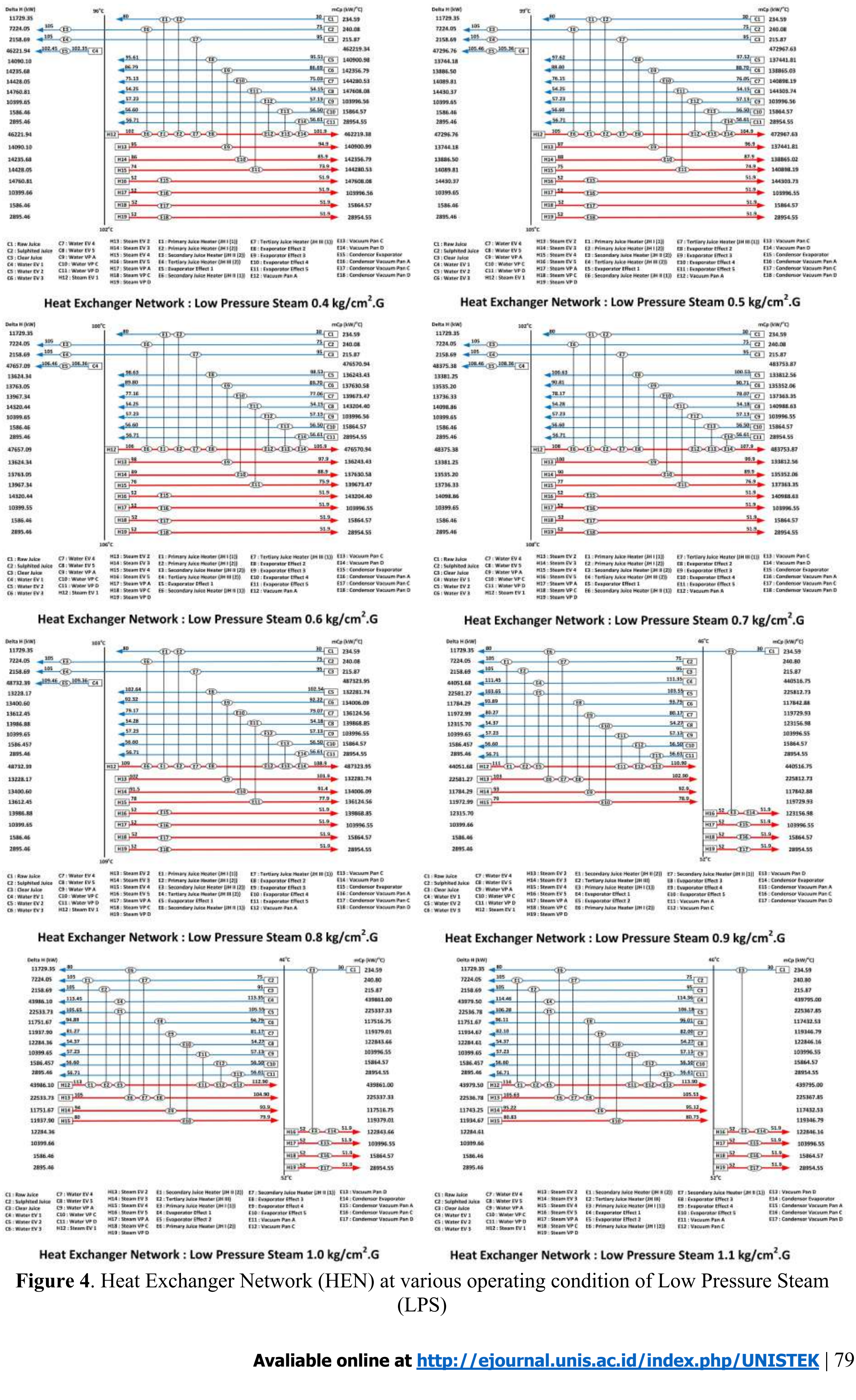

Figure 4. Heat Exchanger Network (HEN) at various operating condition of Low Pressure Steam (LPS)

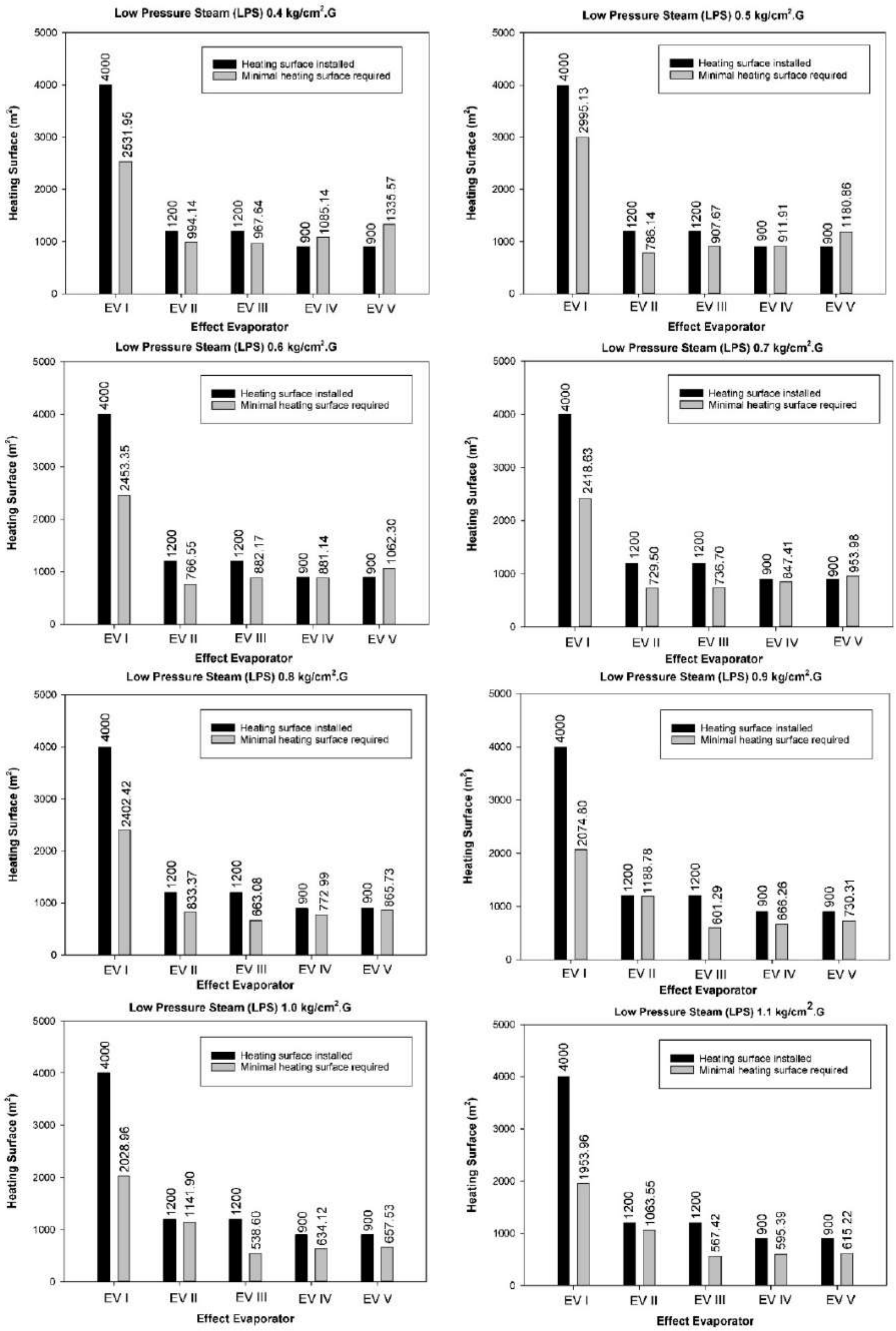

Figure 5. The comparison of installed heating surface vs minimum required heating surface at various operating condition of LPS

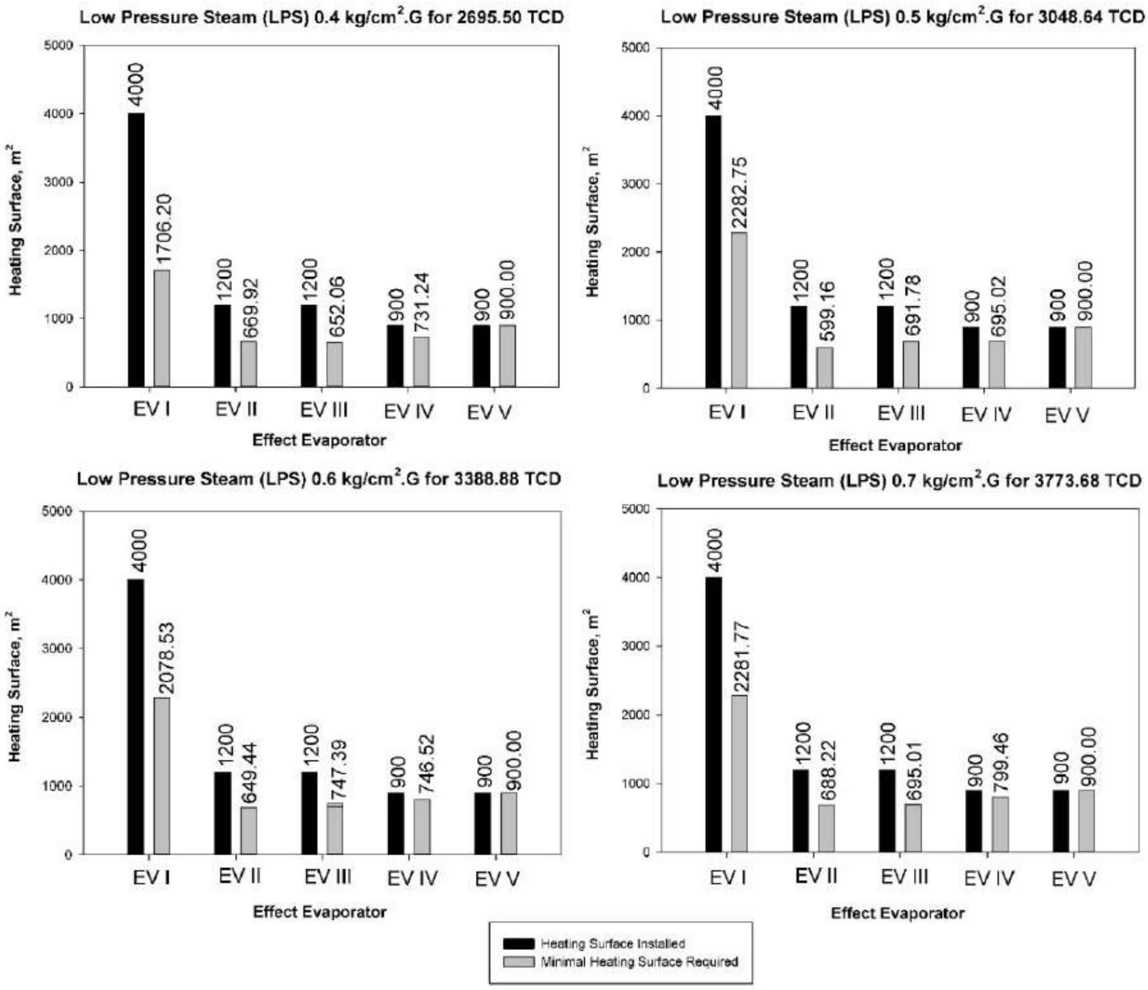

Fig 6. Comparation installed heating surface to required heating surface for LPS at 0.4 kg/cm^2.G – 0.7 kg/cm^2.G after adjusting the cane crushing rate

7. Conclusion

The study of energy integration in sugar cane plant using pinch analysis at various LPS operating condition was succesfully performed. Pinch analysis shows that the maximum energy saving potential was about 30% based on LPS at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G compared to the existing plant condition (0.4 kg/cm^2.G).

The optimized operating condition resulted on higher performance parameters in term of Steam on Cane (SOC) and Steam Economy (SE) up to 43.50% and 2.1, respectively. The best energy distribution scheme for optimum energy demand, based on HEN design for LPS at 0.9 kg/cm^2.G – 1.1 kg/cm^2.G was as follows : 1) Vapour bleeding of evaporator effect 2 can be used to heat primary juice heater 2 (pinch point 46ºC – 80ºC) and secondary juice heater 1 (75ºC – 90ºC); 2) Vapour bleeding of evaporator effect 1 can be used for heating secondary juice heater 2 (90ºC – 105ºC), vacuum pan A, C and D, and tertiary juice heater (95ºC – 105ºC); 3) Vapour bleeding of evaporator effect 5 can be used to heat the primary juice heater 1 (30ºC to pinch point 46ºC); 4) Hot external utility was only from LPS to evaporator effect 1; 5) Cold external utilities were installed in condenser of vacuum pan A, C and D also condenser of last effect evaporator after heating primary juice heater 1.

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