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Simultaneous Optimization of Short-Term Scheduling and Heat Integration Schemes for Multipurpose Batch Plants

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A new synthesis methodology is developed to optimize process scheduling and direct heat integration schemes for multipurpose batch plants simultaneously. Firstly, the concept of associated task is introduced to describe the heat transfer requirements of production tasks and an improved State-Tasks-Network representation is adopted to capture all streams-streams, units-streams and units-units heat integration opportunities. Besides, the detailed design of heat transfer schemes and time sharing mechanism of heat exchangers are also involved in the proposed framework by considering heat transfer tasks-units allocation constraints. Then, a mixed integer linear programming (MILP) model is formulated to maximize profit. It should be noted that the trade-off between utility consumption and equipment cost has been taken into account. At last, an illustrative example is presented to demonstrate the validity and advantages of the proposed approach.

1. Introduction

The emphasis on process sustainability has incentivized academics and industries to develop different energy recovery methodologies for batch processes in the past two decades, such as Pinch technology and Mathematical programming approaches. Due to the complexity caused by time dimension coupling, most of previous methods explored opportunities for heat integration under predefined production schedule, which always lead to suboptimal configurations (Halim and Srinivasan, 2009). Gradually, simultaneous consideration of production scheduling and heat recovery opportunity becomes more attractive. Barbosa-Póvoa et al. (2001) studied the economic savings in utility requirements while considering possible direct plant heat integration with associated costs of the involved auxiliary equipments. Adonyi et al. (2003) introduced S-graph approach to derive an effective algorithm for solving batch process scheduling problem with one to one energy integration. Then Holczinger et al. (2012) further improved this methodology by allowing heat exchange between one stream to multiple streams. Majozi (2006) proposed a continuous time framework to determine the production schedule that is concomitant with direct process-process heat integration for multipurpose batch plants. Later, a more generalized superstructure including indirect heat integration was developed by Seid and Majozi (2014). Castro et al. (2015) proposed a new continuous-based MILP formulation to handle stream to stream heat exchange matches for single stage multiproduct batch plants. All of aforementioned approaches considered heat integration schemes incompletely and heat exchanger is present for each integration pairs.

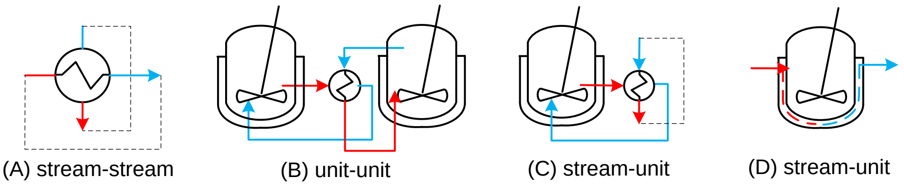
(A) stream-stream
(B) unit-unit
(C) stream-unit
(D) stream-unit

Figure 1: Four types of heat integration schemes for multipurpose batch plant

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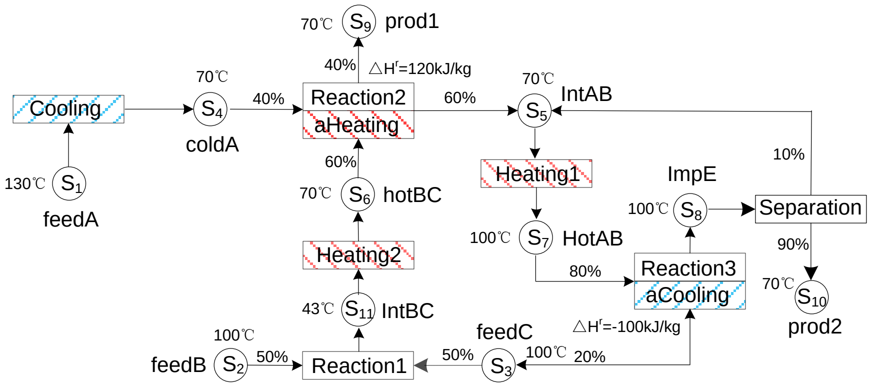

Figure 2: An improved STN involving associated tasks for illustrated example

In this work, four types of heat integration schemes, as illustrated in Figure 1, are all taken into consideration. Furthermore, exchanger timing sharing mechanism is also involved in the proposed framework. In previous literatures, the heat requirements of reaction processes were replaced by the enthalpy change of process streams, which is unreasonable in a situation where reactions run without temperature control. A concept of associated task is introduced to describe the heat transfer requirements for production tasks (reaction and/or separation), such as 'aHeating' task for Reaction2 in Figure 2. Based on the improved State Task Network (STN), all heat integration schemes could be represented by the matches between heat exchange tasks pairs and the heat transfer equipments.

2. Problem statement

The problem considered in this paper can be stated as follows. Given: (1) Production scheduling data; (2) Data required for heat integration including inlet / outlet temperature of tasks and utilities, enthalpy of reactions, material heat capacity and minimum allowable temperature differences; (3) Processing recipe and the corresponding relationships between tasks and units; (4) Costs of utilities, materials and heat exchange equipments, selling price of final products. Determine: An optimal production schedule and heat integration schemes to achieve maximum profit.

The following hypotheses are presented for this problem: (1) A heating/cooling task can match with one or multiple cooling/heating tasks, but only one tasks-pair can occur in a specified heat transfer equipment at each event point p ; (2) Duration of each task is predefined as a parameter.

3. Mathematical model

3.1 Sets

I: tasks; I_j: tasks which can occur in unit j ; I_{ac}: associated cooling tasks; I_{ah}: associated heating tasks; I_c: stream cooling tasks; I_h: stream heating tasks; I_{pp}: processing tasks; I_{ppa}: processing tasks that have associated tasks; I_a^{ippa}: associated task of processing task i_{ppa}; J: units; J_i: units which are suitable for performing task i ; J_{ec}: coolers; J_{eh}: heaters; J_{pp}: processing units; J_{er}: heat exchangers; J_a: associated units; J_a^{jpp}: associated unit of processing unit j_{pp} ; P: event points; S: states; $I_{hh}=I_{ah}\cup I_h$; $I_{cc}=I_{ac}\cup I_c$; $I_a=I_{ac}\cup I_{ah}$;

3.2 Constraints

The proposed new synthesis procedure is formulated as a mixed-integer linear programming, which could be divided into four blocks: sequencing of production tasks, associated task constraints, heat integration constraints and heat exchange equipment constraints. Due to space limitations, the reader is referred to the work of Ierapetritou and Floudas (1998) for the scheduling constraints of production.

Associated task constraints:

These parts of constraints describe the relationship between processing tasks and its associated tasks.

(1) Associated task allocation constraints:

When processing task occurs in the processing unit, its associated task can be performed in the associated unit and heat exchangers simultaneously.

$$\frac{1}{\mathrm{M}}(wv_{i_a^{ippa},j_a^{jpp},p} + \sum_{j_{er}\in \mathrm{J_{er}}} wvv_{i_a^{ippa},j_{pp},j_{er},p}) \le wv_{i_{ppa},j_{pp},p} \le wv_{i_a^{ippa},j_a^{jpp},p} + \sum_{j_{er}\in \mathrm{J_{er}}} wvv_{i_a^{ippa},j_{pp},j_{er},p}$$
$$,i_{ppa}\in \mathrm{I_{ppa}}, j_{pp}\in \mathrm{J_{pp}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_a^{jpp}\in \mathrm{J_a^{jpp}}, p\in \mathrm{P} \tag{1}$$

where, $wv_{i,j,p}$ is a binary variable signifying the beginning of task i in unit j at event point p, $wvv_{i,j,j',p}$ is a binary variable signifying the beginning of tasks i in unit j' at event point p when multipurpose problem exist. M is a large number.
(2) Mass balances constraints:

$$B_{i_{ppa},j_{pp},p} = B_{i_a^{ippa},j_a^{jpp},p} + \sum_{j_{er}\in J_{er}} BB_{i_a^{ippa},j_{pp},j_{er},p}, i_{ppa}\in \mathrm{I_{ppa}}, j_{pp}\in \mathrm{J_{pp}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_a^{jpp}\in \mathrm{J_a^{jpp}}, p\in \mathrm{P} \tag{2}$$

where, $B_{i,j,p}$ / $BB_{i,j,j',p}$ is the amount of material processed.
(3) Energy calculation:

$$Q_{i_a j,p} = \left|B_{i_a,j,p}\Delta \mathrm{H}_{i_a}^{r}\right|, i_a\in \mathrm{I_a}, j\in \mathrm{J_i}, p\in \mathrm{P} \tag{3}$$

where, $Q_{i,j,p}$ is energy required by task i in unit j at event point p, ΔH_i^r is reaction enthalpy of task i.
(4) Associated task timing constraints:

$$T^s_{i_{ppa},j_{pp},p} \ge T^s_{i_a^{ippa},j,p} - \mathrm{M}\left(2 - wv_{i_{ppa},j_{pp},p} - wv_{i_a^{ippa},j,p}\right), i_{ppa}\in \mathrm{I_{ppa}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_{pp}\in \mathrm{J_{pp}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{4}$$

$$T^s_{i_{ppa},j_{pp},p} \le T^s_{i_a^{ippa},j,p} + \mathrm{M}\left(2 - wv_{i_{ppa},j_{pp},p} - wv_{i_a^{ippa},j,p}\right), i_{ppa}\in \mathrm{I_{ppa}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_{pp}\in \mathrm{J_{pp}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{5}$$

$$T^f_{i_{ppa},j_{pp},p} \ge T^f_{i_a^{ippa},j,p} - \mathrm{M}\left(2 - wv_{i_{ppa},j_{pp},p} - wv_{i_a^{ippa},j,p}\right), i_{ppa}\in \mathrm{I_{ppa}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_{pp}\in \mathrm{J_{pp}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{6}$$

$$T^f_{i_{ppa},j_{pp},p} \le T^f_{i_a^{ippa},j,p} + \mathrm{M}\left(2 - wv_{i_{ppa},j_{pp},p} - wv_{i_a^{ippa},j,p}\right), i_{ppa}\in \mathrm{I_{ppa}}, i_a^{ippa}\in \mathrm{I_a^{ippa}}, j_{pp}\in \mathrm{J_{pp}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{7}$$

where: $T^s_{i,j,p}$ / $T^f_{i,j,p}$ is starting/ finishing time of task i in unit j at event point p.
Heat integration constraints:
(1) Timing constraints:
At an event point p, the finishing time of heating and cooling tasks which need heat integration should be identical. Relaxation has been made on starting time of heating and cooling tasks.

$$T^f_{i_{hh},j,p} \ge T^f_{i_{cc},j,p} - \mathrm{M}\left(2 - wv_{i_{hh},j,p} - wv_{i_{cc},j,p}\right), i_{hh}\in \mathrm{I_{hh}}, i_{cc}\in \mathrm{I_{cc}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{8}$$

$$T^f_{i_{hh},j,p} \le T^f_{i_{cc},j,p} + \mathrm{M}\left(2 - wv_{i_{hh},j,p} - wv_{i_{cc},j,p}\right), i_{hh}\in \mathrm{I_{hh}}, i_{cc}\in \mathrm{I_{cc}}, j\in \mathrm{J_{er}UJ_a}, p\in \mathrm{P} \tag{9}$$

(2) Energy calculation:

$$Q_{i,j,p} = \left|B_{i,j,p}\,\mathrm{cp}_i\left(T_i^{in} - T_i^{out}\right)\right|, i\in \mathrm{I_hUI_c}, j\in \mathrm{J_i}, p\in \mathrm{P} \tag{10}$$

where, cp_i is specific heat capacity of task i, and, T_i^{in} / T_i^{out} is inlet/ outlet temperature of task i.
(3) Feasibility constraints :
When heat integration occurs in a specific heat exchange unit at event point p, the average heat flow of heating and cooling tasks should be equal.

$$\sum_{i_{hh}\in I_{hh}} \left(Q_{i_{hh},j_{er},p}/\alpha_{i_{hh}}\right) = \sum_{i_{cc}\in I_{cc}} \left(Q_{i_{cc},j_{er},p}/\alpha_{i_{cc}}\right), j\in \mathrm{J_{er}}, p\in \mathrm{P} \tag{11}$$

$$\sum_{i_{ah}\in \mathrm{I_{ah}}} (Q_{i_{ah},j_a,p}/\alpha_{i_{ah}}) \ge \sum_{i_c\in \mathrm{I_c}} (Q_{i_c,j_a,p}/\alpha_{i_c}) - \mathrm{Q_{max}}(1 - wv_{i_c,j_a,p}), j_a\in \mathrm{J_a}, p\in \mathrm{P} \tag{12}$$

$$\sum_{i_{ah}\in \mathrm{I_{ah}}} (Q_{i_{ah},j_a,p}/\alpha_{i_{ah}}) \le \sum_{i_c\in \mathrm{I_c}} (Q_{i_c,j_a,p}/\alpha_{i_c}) + \mathrm{Q_{max}}(1 - wv_{i_c,j_a,p}), j_a\in \mathrm{J_a}, p\in \mathrm{P} \tag{13}$$

where, α_i is constant term in the processing time of task i. Eq(12) and Eq(13) are also applicable to associated cooling tasks and stream heating tasks.

(4) Energy balances constraints:

$$\sum_{i_{cc}\in \mathrm{I_{cc}}} Q^{cw}_{i_{cc},j_{er},p} + \sum_{i_{hh}\in \mathrm{I_{hh}}} Q_{i_{hh},j_{er},p} = \sum_{i_{cc}\in \mathrm{I_{cc}}} Q_{i_{cc},j_{er},p} + \sum_{i_{hh}\in \mathrm{I_{hh}}} Q^{st}_{i_{hh},j_{er},p},\ j_{er}\in \mathrm{J_{er}},\ p\in \mathrm{P} \qquad (14)$$

$$\sum_{i_c\in \mathrm{I_c}} Q^{cw}_{i_c,j_a,p} + \sum_{i_{ah}\in \mathrm{I_{ah}}} Q_{i_{ah},j_a,p} \geq \sum_{i_c\in \mathrm{I_c}} Q_{i_c,j_a,p} + \sum_{i_{ah}\in \mathrm{I_{ah}}} Q^{st}_{i_{ah},j_a,p} - \mathrm{Q_{max}}(1- \sum_{i_{ah}\in \mathrm{I_{ah}}} wv_{i_{ah},j_a,p}),\ j_a\in \mathrm{J_a},\ p\in \mathrm{P} \qquad (15)$$

$$\sum_{i_c\in \mathrm{I_c}} Q^{cw}_{i_c,j_a,p} + \sum_{i_{ah}\in \mathrm{I_{ah}}} Q_{i_{ah},j_a,p} \leq \sum_{i_c\in \mathrm{I_c}} Q_{i_c,j_a,p} + \sum_{i_{ah}\in \mathrm{I_{ah}}} Q^{st}_{i_{ah},j_a,p} + \mathrm{Q_{max}}(1- \sum_{i_{ah}\in \mathrm{I_{ah}}} wv_{i_{ah},j_a,p}),\ j_a\in \mathrm{J_a},\ p\in \mathrm{P} \qquad (16)$$

Eq(15) and Eq(16) are also applicable to associated cooling tasks and stream heating tasks.
(5) Minimum thermal driving forces constraints:

$$T^{in}_{i_{cc}} - T^{out}_{i_{hh}} \geq \Delta \mathrm{T_{min}} - \mathrm{M}\left(2 - wv_{i_{cc},j,p} - wv_{i_{hh},j,p}\right),\ i_{hh}\in \mathrm{I_{hh}},\ i_{cc}\in \mathrm{I_{cc}},\ j\in \mathrm{J_{er}} \cup \mathrm{J_a},\ p\in \mathrm{P} \qquad (17)$$

$$T^{out}_{i_{cc}} - T^{in}_{i_{hh}} \geq \Delta \mathrm{T_{min}} - \mathrm{M}\left(2 - wv_{i_{cc},j,p} - wv_{i_{hh},j,p}\right),\ i_{hh}\in \mathrm{I_{hh}},\ i_{cc}\in \mathrm{I_{cc}},\ j\in \mathrm{J_{er}} \cup \mathrm{J_a},\ p\in \mathrm{P} \qquad (18)$$

where, $\Delta \mathrm{T_{min}}$ is the minimum temperature differences.
Heat exchange equipment allocation constraints:
At an event point *p*, one heating task can only be integrated with one cooling task in a heat exchanger.

$$\sum_{i_{hh}\in \mathrm{I_{hh}}} wv_{i_{hh},j_{er},p} = \sum_{i_{cc}\in \mathrm{I_{cc}}} wv_{i_{cc},j_{er},p},\ j_{er}\in \mathrm{J_{er}},\ p\in \mathrm{P} \qquad (19)$$

Eq(20) and Eq(21) describe that heat integration between streams tasks and associated tasks are available in the associated units.

$$wv_{i_{ac},j_a,p} \geq \sum_{i_h\in \mathrm{I_h}} wv_{i_h,j_a,p},\ i_{ac}\in \mathrm{I_{ac}},\ j_a\in \mathrm{J_a},\ p\in \mathrm{P} \qquad (20)$$

$$wv_{i_{ah},j_a,p} \geq \sum_{i_c\in \mathrm{I_c}} wv_{i_c,j_a,p},\ i_{ah}\in \mathrm{I_{ah}},\ j_a\in \mathrm{J_a},\ p\in \mathrm{P} \qquad (21)$$

$$y_j \geq \frac{1}{\mathrm{M}} \sum_{p\in \mathrm{P}} \sum_{i\in \mathrm{I}} wv_{i,j,p},\ j\in \mathrm{J_{eh}} \cup \mathrm{J_{ec}} \cup \mathrm{J_{er}} \cup \mathrm{J_a} \qquad (22)$$

where, y_j is a binary variable signifying if heat exchange unit is used.

3.3 Objective function

$$z = \sum_{p\in \mathrm{P}} \sum_{s\in \mathrm{S}} \mathrm{price_s}\, d_{s,p} - \sum_{p\in \mathrm{P}} \sum_{i_{hh}\in \mathrm{I_{hh}}} \sum_{j\in \mathrm{J_{eh}} \cup \mathrm{J_{er}} \cup \mathrm{J_a}} Q^{st}_{i_{hh},j,p}\, \mathrm{costst} - \sum_{p\in \mathrm{P}} \sum_{i_{cc}\in \mathrm{I_{cc}}} \sum_{j\in \mathrm{J_{ec}} \cup \mathrm{J_{er}} \cup \mathrm{J_a}} Q^{cw}_{i_{cc},j,p}\, \mathrm{costcw} - \sum_{j\in \mathrm{J_{eh}} \cup \mathrm{J_{ec}} \cup \mathrm{J_{er}} \cup \mathrm{J_a}} \mathrm{eq_j}\, y_j \qquad (23)$$

Eq(23) is the objective function in terms of profit maximization. The profit equals to the difference between product revenue and costs of utilities as well as costs of heat exchange equipments. Where, $\mathrm{price_s}$ is the price of state s, $\mathrm{d_{s,p}}$ is the amount of state s being delivered to the market at event point p, $\mathrm{costst/\,costcw}$ is the cost of steam/ cooling water and $\mathrm{eq_j}$ is the cost of each heat exchange equipment in one batch.

4. Example

In order to demonstrate the effectiveness of the proposed framework, one illustrative example with two cases is presented. The improved STN representation of process flowsheet is shown in Figure 2, and Table 1 lists the processing data. Prices of product 1 and 2 are both 10 \$/kg, steam (170 - 160 °C) cost is 1 \$/MJ and cooling water (20 - 30 °C) cost is 0.02 \$/MJ. Minimum thermal driving force has been specified as 10 °C.

Table 1: Data for the illustrative example

Task (i)	Unit (j)	Max batch size(kg)	α_i(h)	Cp(kJ /kg℃)	State	Storage capacity(kg)
Cooling/C	CR/EXR/E1/E2	100	0.8	2.2	S1 feed A	1,000
aCooling/C_a	EXR/ E1/E2	100	0.9	2.4	S2 feed B	1,000
Heating1/H_1	HR/EXR/E1/E2	100	0.8	2.5	S3 feed C	1,000
Heating2/H_2	HR/EXR/E1/E2	100	0.8	2.9	S4 cold A	100
aHeating/H_a	EXR/ E1/E2	100	1.2	3.0	S5 Int AB	200
Reaction1/R_1	RR1/RR2	50/80	1	3.5	S6 hot BC	150
Reaction2/R_2	RR1/RR2	50/80	1.2	3.0	S7 hot AB	200
Reaction3/R_3	RR1/RR2	50/80	0.9	2.4	S8 Imp E	200
Separation/S	SR	200	1.2	2.8	S9 prod 1	1,000
					S10 prod 2	1,000
					S11 Int BC	150

Table 2: Computational results for the case study

	Literature	Case1	Case2
Product produced(kg)	348.833	348.833	348.833
Steam(MJ)	59.2	59.2	77.95
Cooling water(MJ)	17.522	17.522	36.273
Number of heat exchange equipment	20	5	4
Profit($)	3,368.783	3,378.783	3,329.657

The annual cost of each heat exchange equipment is 10,000 $ in case 1, but 20,000 $ in case 2. The time horizon of each batch cycle is 8 h and total number of batch cycles every year is 1,000.

Firstly, the example is solved by the new formulation with combining Seid and Majozi (2014)'s method and our improved STN representation. And the optimized Gantt chart and heat exchange network as shown in Figure 3 indicate that all heat integration opportunities could be captured with 20 heat transfer equipments used. Figure 4 shows the optimization results generated by the proposed model. The readers could easily find the production sequences, heat integration schemes and detailed implementation structures in a single Gantt chart. As shown in Table 2, our configuration of case 1 obtains more profits and only 5 heat exchange equipments were required. This improvement benefits from equipment cost consideration and timing sharing of equipment, such as heat exchanger EXR has been used 4 times and associated unit jacket E1 and E2 has been used 3 and 5 times respectively.

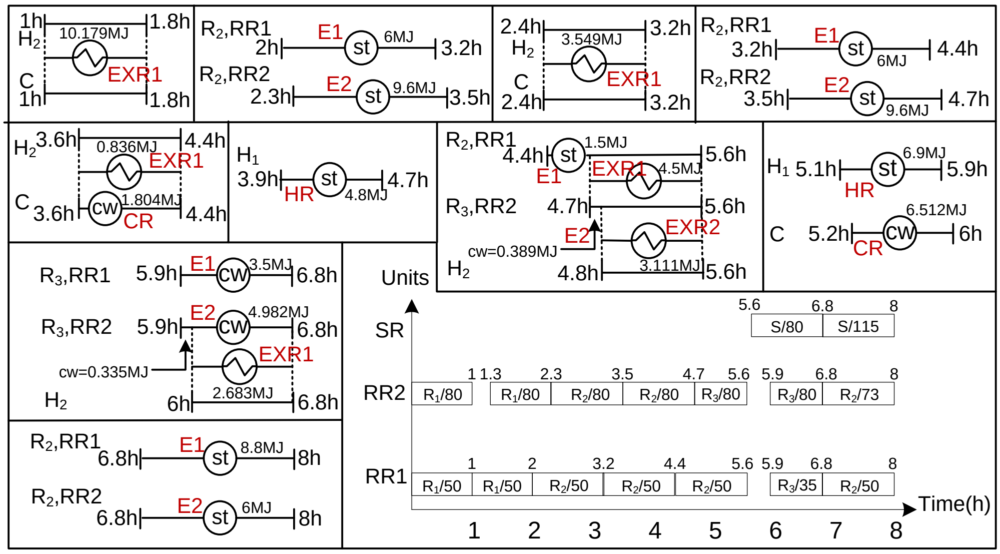

Figure 3: Gantt chart and heat integration schemes by modified Seid and Majozi's method (2014)

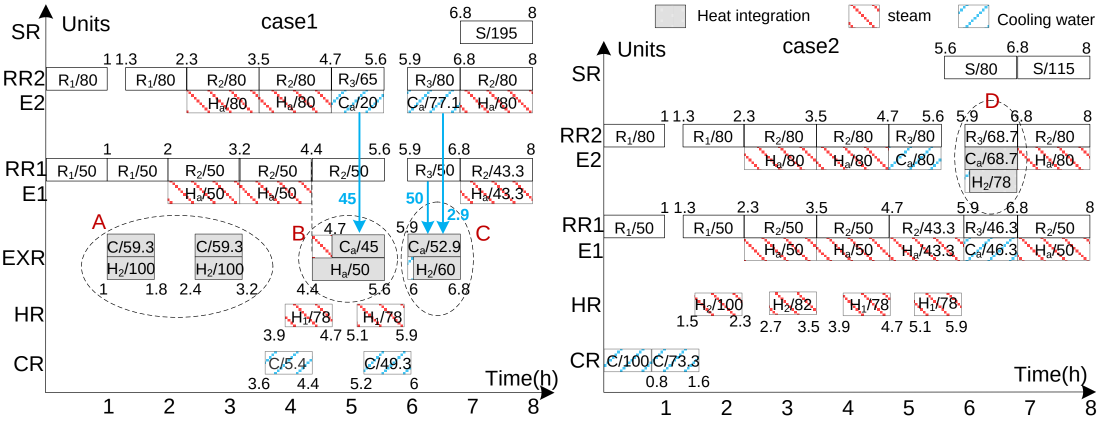

Figure 4: Gantt chart of our optimal solution for case1 and case 2

In Figure 4, dashed circle (A), (B), (C) represents stream-stream, unit-unit, unit-stream heat integration schemes respectively. In circle (B), associate task of R3 is satisfied by cooling water in an associated unit jacket E2 and the other parts is heat integrated with associated heating task in a heat exchanger EXR. In circle (C), Reaction3 occurs in two reactors simultaneously and both associated cooling task matches with stream heating task H2 in a heat exchanger EXR. All aforementioned configurations have never been involved and carefully studied in previous literatures. Case 2 shows the impact of heat transfer equipment's cost on the scheduling and heat integration. With the increasing equipment's cost, the number of heat transfer equipment decreases while the utility consumption increases. At this time, only one heat integration scheme occurs (D).

5. Conclusion

This article presents a general framework to integrate short-term scheduling and direct heat integration in multipurpose batch plants. Four types of heat integration schemes are incorporated into the synthesis framework. And an improved State-Tasks-Network is developed to capture these types of heat integration through introducing a novel concept of associated task which can describe the heat transfer requirements for production tasks. In addition, time sharing mechanism of heat exchange equipment is also taken into account to cut off equipment cost. According to the proposed methodology, a mixed integer linear programming (MILP) model is formulated to achieve maximum profit. The example results clearly show that the methodology can achieve effective trade-offs among production revenue, utility consumption and equipment cost.

Acknowledgments

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Reference

Adonyi R., Romero J., Puigjaner L., Friedler F., 2003, Incorporating heat integration in batch process scheduling, Applied Thermal Engineering, 23, 1743-1762.

Barbosa-Póvoa A.P.F.D., Pinto T., Novais A.Q., 2001, Optimal design of heat-integrated multipurpose batch facilities: a mixed-integer mathematical formulation, Computers & Chemical Engineering, 25, 547-559.

Castro P.M., Custódio B., Matos H.A., 2015, Optimal scheduling of single stage batch plants with direct heat integration, Computers & Chemical Engineering, 82, 172-185.

Halim I., Srinivasan R., 2009, Sequential Methodology for Scheduling of Heat-integrated Batch Plants, Industrial & Engineering Chemistry Research, 48, 8551-8565.

Holczinger T., Hegyháti M., Friedler F., 2012, Simultaneous heat integration and batch process scheduling, Chemical Engineering Transactions, 29, 337-342.

Ierapetritou M.G., Floudas C.A., 1998, Effective Continuous-Time Formulation for Short-Term Scheduling. 1. Multipurpose Batch Processes, Industrial & Engineering Chemistry Research, 37, 4341-435.

Majozi T., 2006, Heat integration of multipurpose batch plants using a continuous-time framework, Applied Thermal Engineering, 26, 1369-1377.

Seid R.E., Majozi T., 2014, Heat integration in multipurpose batch plants using a robust scheduling framework, Energy, 71, 302-320.