

Heat-Integrated Design for Natural Gas Processing

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Snížení spotřeby tepla při úpravě zemního plynu

Analysis and design of chemical technological processes is faster and more effective when using simulations. The greatest advantage of simulations consists in saving of costs on experiments with production facility that are for the most part substituted by calculations. We have illustrated flowsheet simulator usage with a case study. The simulation of an expander plant to recover the heavy components from natural gas is presented and heat-integrated process is proposed.

Key words: heat-integrated process, Natural Gas Processing

Introduction

Simulation is an important tool for analysis and design of chemical technological processes. Gas processing is believed to be an area where simulations could be used very advantageously because hydrocarbons and other organic compounds do not cause such troubles at calculations as strong polar and strong dissociated compounds. In our work we have used simulator HYSYS.Process 2.2 [1] [2] that is intended particularly for steady state continuous chemical processes simulation. It is provided with simple and user friendly graphics interface. Education of simulator's user needs circa 10 – 20 hours. However, after that, activities that still demanded weeks and months for creating of models and programs in any programming language need only tens of minutes or a few hours at most.

Process Description

Natural gas has to be processed before it is transported or delivered to the consumer. Technology of gas processing depends on composition of crude gas. Natural gas from high-pressure wells is usually passed through field separators at the well to remove hydrocarbon condensate and water. Then the hydrogen sulfide must be removed (called sweetening the gas). Natural gasoline, butane, and propane are usually present in the gas, and gas processing plants are required for the recovery of these liquefiable constituents. In our case study we have created simulation model of recovery of natural gas liquids from gas that can bring significant additional profit.

It is required to process natural gas stream at 4536 kgmole/h, 21 °C, 1 MPa and composition in Tab. 1. The gaseous product is required to be at 1 MPa, with at least 4472 kgmole/h of nC_4 and lighter species, and a combined mole percentage at least 99.5 %. The liquid product is required to be at least 1 MPa, with at least 30.6 kgmole/h of nC_5 and nC_6 and a combined mole percentage at least 75 %.

Tab. 1: Molar Flow Rates of the Feed, Gas, and Liquid Product Streams (in kgmole/h)

| X Component | Feed (stream SZP) | Gas (stream ZP) | Liquid (stream S11) |
|----------------|----------------------|--------------------|------------------------|
| N ₂ | 95.7 | 95.7 | 0 |
| C ₁ | 3754 | 3754 | 0 |
| C ₂ | 395.1 | 395.1 | 0 |
| C ₃ | 186.4 | 186.1 | 0.3 |
| nC_4 | 64 | 41.9 | 22.0 |
| nC_5 | 25.9 | 5.2 | 20.7 |
| nC_6 | 15 | 0.9 | 14.1 |
| Total | 4536 | 4478.9 | 57.1 |

Instead of technological scheme we can show structure of the simulated process on the process flow diagram we have created in HYSYS (Fig. 1). The feed is compressed to 2.3 MPa, cooled to 38 °C using cooling water (E-1A), and to -26 °C using refrigerant (E-1B), before entering the flash vessel, (S-1), at 2.1 MPa. Its vapor effluent and liquid product are heated (E-2A, E-2B), to 27 °C. The latter enters the flash vessel, (S-2), at

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2.05 MPa. Its liquid effluent is fed to the distillation column, K-1, which is designed to remove most of the propane in the overhead stream. It has twelve theoretical trays (not counting reboiler and condenser), with the feed to the fourth tray from the top, and recovers 99 % of nC_5 in the bottom products and 99 % of nC_3 in the distillate.

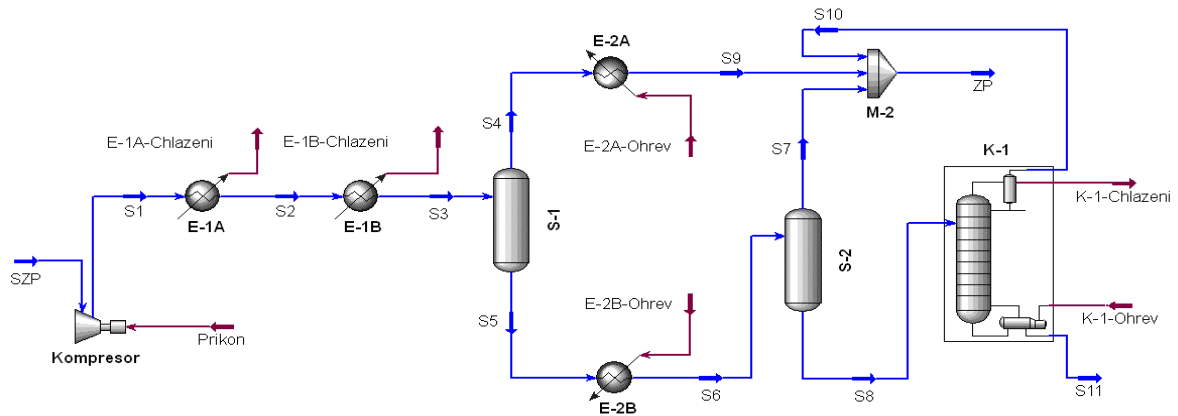


Fig. 1 Process flow diagram for the natural gas processing

Simulation Model

The simulation is built using these basic steps:

1. Create a unit set.
2. Choose a property package (we used Peng-Robinson's variant of Redlich-Kwong equation).
3. Select the components.
4. Create and specify the feed streams.
5. Install and define the unit operations prior to the column (Because we are interested only in how much energy is required to cool or heat a process stream we used a simplified model of heat exchanger COOLER for E-1A, E-1B and HEATER for E-2A, E-2B. For modeling of flash vessels S-1, S-2 we used model SEPARATOR that splits the two-phase inlet stream into its vapor and liquid phases, into one vapor and one liquid product stream.)
6. Install and define the column.

Installing the column is the most difficult step of building simulation model, because multi-stage fractionation tower is the most complex unit operation that HYSYS simulates. It consists of a series of equilibrium or non-equilibrium flash stages and has many parameters. For K-1 we used model DISTILLATION COLUMN. It is a special type of subflowsheet that contains equipment and streams, and exchanges information with the parent flowsheet through the connected internal and external streams. In general, it has three degrees of freedom we can use for fruition of desired component separation - a combined mole percentage of nC_5 and nC_6 at least 75 % in the liquid product. However, by specifying zero overhead liquid flow (full reflux condenser) one degree of freedom was eliminated. For the two remaining specifications from more than 25 available specs we examined column reflux ratio, column component flow rate and column component fraction. The reflux ratio is defined as the ratio of the liquid returning to the tray section divided by the total flow of the products. Component flow rate allows specifying the flow rate of any component, or the total flow rate for any set of components for the flow leaving any stage. Component fraction allows specifying the mole, mass or volume fraction in the liquid or vapor phase for any stage.

Tab. 2: Molar Flow Rates of the Gas, and Liquid Product Streams (in kgmole/h)

| Component | Model A | | Model B | |
|----------------|--------------------|------------------------|--------------------|------------------------|
| | Gas (stream ZP) | Liquid (stream S11) | Gas (stream ZP) | Liquid (stream S11) |
| N ₂ | 95.7 | 0 | 95.7 | 0 |
| C ₁ | 3754 | 0 | 3754 | 0 |
| C ₂ | 395.1 | 0 | 395.1 | 0 |
| C ₃ | 186.4 | 0 | 186.4 | 0 |
| nC_4 | 53.4 | 10.5 | 53.5 | 10.5 |
| nC_5 | 5.1 | 20.7 | 5.1 | 20.7 |
| nC_6 | 0.9 | 14.1 | 0.9 | 14.1 |
| Total | 4490.6 | 45.4 | 4490.6 | 45.4 |

We have built two models. In model A we have determined as default specifications reflux ratio and component fraction – combined mole percentage of C1 – C3 in overhead products. In model B we have determined as default specifications reflux ratio and component flow rate – molar flow of *n*-Butane in overhead products. The optimal reflux ratio was found in both models 5, the calculated C1 – C3 fraction was 71.6 % and the calculated flow of *n*-Butane was 21.1 kgmole/h.

Composition of both gaseous and liquid products satisfies requirements of problem (see Tab. 1) and is represented in Tab. 2

Heat-Integrated Process

Process flow diagram of heat-integrated process we have created in HYSYS is shown in Fig. 2. Structure of the process was modified so that heat exchangers for heating of outlet streams of the first separator **S-1** economize heat of gas heated in compressor. It was necessary to use the full value HEAT EXCHANGER weighed design model that calculates the overall exchanger UA (product of the overall heat transfer coefficient and the total area available for heat transfer). In this configuration, the hot stream, S2, has supply and target temperatures of 73 °C and - 26 °C, and the two cold streams, each have supply and target temperatures of - 26 °C to 27 °C, respectively. The hot stream is split and used to heat two cold streams, with a minimum approach temperature difference of 10 °C. The split ratio is chosen to obtain isothermal mixing in the mixer, **M-1** with the help of ADJUST operation that

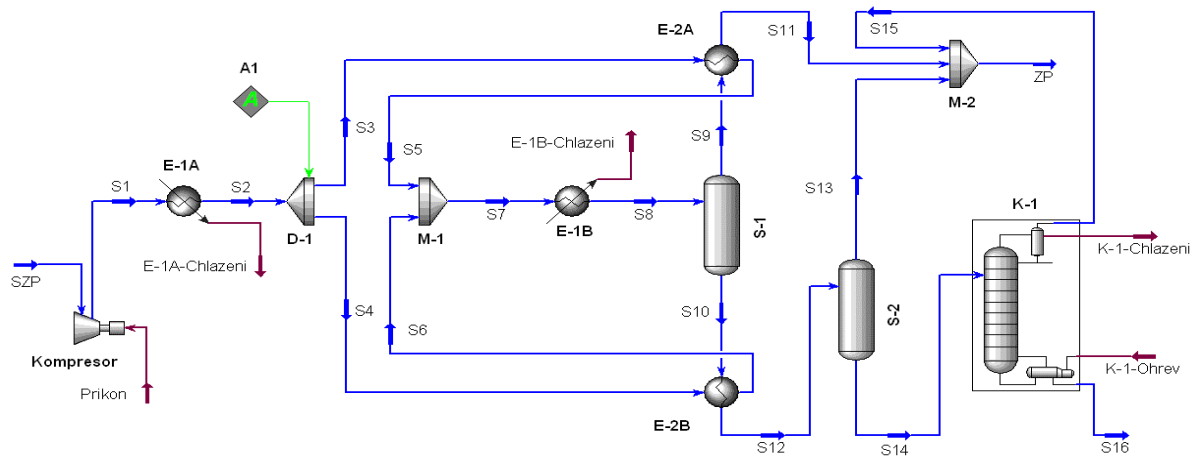


Fig. 2 Process flow diagram for heat-integrated process

varies the ratio of the outlet stream flow of TEE operation D-1 to meet the required zero temperature difference that is calculated in HYSYS SPREADSHEET operation. Tab. 3 compares the energy requirements of the original design with the heat integrated design. The latter has no external heating requirements (apart from the column K-1), and its refrigeration load is only 28 % of that of the original design. Energy saving makes up approx. 3 MW refrigeration.

Tab. 3: Comparison of the energy requirements in MW of the original design with the heat integrated design

| Exchanger | Initial Design | | | Heat-Integrated Design | | |
|-----------|----------------|---------------|-------|------------------------|---------------|-------|
| | Refrigerant | Cooling Water | Steam | Refrigerant | Cooling Water | Steam |
| E-1A | - | 2.01 | - | - | 2.01 | - |
| E-1B | 4.14 | - | - | 1.14 | - | - |
| E-2A | - | - | 2.70 | - | - | - |
| E-2B | - | - | 0.29 | - | - | - |
| Total | 4.14 | 2.01 | 3.99 | 1.14 | 2.01 | 0 |

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References

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