PEP Review 2016-01

Carbon monoxide production from syngas via cryogenic partial condensation process

Jonny Goyal, Principal Analyst

Abstract
Carbon monoxide is an industrial gas that has many applications in bulk chemicals manufacturing. Over 90% of carbon monoxide is used in the form of synthesis gas (or syngas) for the production of ammonia, hydrogen, and methanol. The rest is consumed directly as carbon monoxide for the production of phosgene (COC₁₂), acrylic acid (CH₂=CHCOOH), acetic acid (CH₃COOH), dimethyl formamide, propionic acid, pivalic acid, and many other copolymers. These bulk chemicals have a large market and thus play an important role in a country’s economy.

Typically, carbon monoxide coexists with hydrogen as a mixture gas. To obtain pure carbon monoxide (CO), it is separated from the mixture gas. Different technologies are used, such as cryogenic separation, pressure swing adsorption, membrane separation, and salt solution absorption. The design of a particular system is determined primarily by the feed gas composition, inlet pressure, and by the purity and pressure specifications for the separated gases. The design also depends on whether the process objective is to minimize energy requirements or capital cost or to optimize both; considerable variation is possible in the number and arrangement of equipment configuration, heat interchange, and expansion and/or compression steps.

The cryogenic partial condensation process is one well-defined and widely used commercial route to carbon monoxide (CO) production. This process produces commercial-grade carbon monoxide (98–99% purity) and also hydrogen (97–98% purity). While the simplicity of this process makes it attractive, its refrigeration requirement is significant. This PEP review focuses on the cryogenic partial condensation process using syngas from different sources: one from steam methane reforming (with the H₂:CO ratio at 3:1) and another from coal gasification (with the H₂:CO ratio at 1.8:1). The purpose of taking two different H₂:CO sources is to design a system that can widely accept the variation in syngas composition while keeping the same equipment configuration with minimal energy and capital cost requirements.

Our design is based on technical information and data available from patents assigned to Linde, Air Liquide, Air Products and Chemicals, etc., as well as different literature surveys. The design provided in this report is based on a typical Linde technology approach with some equipment restructure. The cryogenic partial condensation process is reviewed, the industry status of carbon monoxide is updated, and a summary is provided of both cases in terms of comparative economics.

While the process presented herein is PEP’s independent interpretation of the companies’ patent literature and may not reflect in whole or in part the actual plant configuration, we do believe that they are sufficiently representative of plant conceptual process designs.
## Contents

1 Introduction 6  
2 Carbon monoxide sources and production 7  
   Sources 7  
      Laboratory preparation 7  
      Industrial production 7  
      Steam reforming 8  
         Partial oxidation of hydrocarbons, petroleum coke, or coal 8  
         Auto-thermal reforming of natural gas 8  
         Gasification of coal or biomass 8  
   Production (carbon monoxide purification) 9  
      Cryogenic separation—Partial condensation process 9  
      Cryogenic separation—Liquid methane wash process 11  
      Pressure swing adsorption 12  
      Membrane separation process 13  
      Salt solution absorption—COSORB process 14  
      Copper–ammonium salt absorption process 16  
3 Industry status—Carbon monoxide use 18  
   Acetic acid 18  
   Phosgene 18  
      Synthesis of carbonates 18  
      Synthesis of isocyanates 18  
      Synthesis of acid chlorides and esters 19  
   Formic acid 19  
   Dimethylformamide 19  
   Copolymers of ethylene/carbon monoxide 20  
   Propionic acid 20  
   Pivalic acid 20  
   Acrylic acid 21  
4 Chemistry 22  
   Fischer-Tropsch 22  
   Methanation 22  
   Hydroformylation 22  
   Polymerization 23  
   Carbonylation 23  
   Carboalkoxylation 23  
   Hydroxycarbonylation 24  
   Isocyanate synthesis 24  
   Inorganic reactions 24  
5 Cryogenic separation of carbon monoxide from synthesis gas 25  
   Technology review 25  
      Some examples 25  
6 Process description 27  
   Cryogenic separation using syngas from SMR (case I) 27  
   Cryogenic separation using syngas from coal gasification (case II) 31  
   Process discussions 35  
7 Cost estimates 36  
   Capital cost 36  
      Case I 36  
      Case II 36
Table 4  Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Major equipment
Table 5  Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Utility summary
Table 6  Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Major stream flows
Table 7  Carbon monoxide separation via partial condensation process using syngas from SMR (case I)—Total capital investment
Table 8  Carbon monoxide separation via partial condensation process using syngas from SMR (case I)—Capital investment by section
Table 9  Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Total capital investment
Table 10 Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Capital investment by section
Table 11 Carbon monoxide separation via partial condensation process using syngas from SMR (case I)—Production cost
Table 12 Carbon monoxide separation via partial condensation process using syngas from coal gasification (case II)—Production cost
Table 13 Carbon monoxide cryogenic process via partial condensation using syngas from SMR (case I)
Table 14 Carbon monoxide cryogenic process via partial condensation using syngas from coal gasification (case II)