Phenol Production by ExxonMobil 3-step Process

PEP Review 2020-02
April 2020
Abstract

In 2017, the world demand for phenol was ~12.8 million tonnes. The three largest contributors to the worldwide capacity in 2017 were Northeast Asia, United States, and Western Europe. The largest end-use for phenol is in the manufacture of bisphenol A (BPA). Although it is under regulatory pressure for health and safety reasons, BPA is the key building block for making polycarbonate and epoxy resins. The next largest use for phenol is in the production of phenol–formaldehyde (PF) resins. PF resins are used primarily in wood adhesives, for example, for bonding the layers of plies in exterior plywood.

Since its commercialization in the early 1950s, the cumene hydroperoxide (CHP) process has become the dominant technology for phenol production. Well over 90% of the world phenol production is based on this technology. A drawback of this process is the substantial production of acetone coproduct. While well-established global markets for acetone exist, the demand for this coproduct has not always kept pace with the demand for phenol in certain regions. This has been a factor stimulating interest in new “non-coproduct” phenol technologies, which would produce phenol directly from benzene.

More recently, ExxonMobil has developed a 3-step route from benzene to phenol that co-produces cyclohexanone, which has excellent commercial value and market compared to acetone. This PEP review evaluates the ExxonMobil’s 3-step process for the production of phenol, using benzene as feedstock and provide the economics for the process at the US Gulf Coast. The process shows excellent product economics and higher product yield and could be the future phenol production process.

There is no commercial reference available yet for this process, our plant design and economics are based on the patent’s information and the author’s engineering judgement. This review also includes the market status assessment of supply and demand trends for phenol and cyclohexanone, with the iPEP Navigator tool attached to the electronic version of this review as well.
## Contents

1 **Introduction**  
2 **Summary**  
   Exxon’s 3-step phenol process  
   Exxon 3-step process comparison with other commercialized processes  
   Environmental footprint  
3 **Industry status**  
   Phenol  
   Cyclohexanone  
4 **Technology review**  
   Natural recovery  
   Recovery from coal tar and petroleum streams  
   Phenol production on Industrial scale  
   **Patents review**  
   Benzene Hydro-alkylation  
   Poly-cyclohexylbenzenes transalkylation  
   CHB oxidation  
   Hydroperoxide cleavage and separation  
5 **Phenol Production by ExxonMobil 3-step Process**  
   Process design basis  
   **Process description and discussion**  
   Section 100—Benzene Hydro-alkylation and product separation  
   Section 200—Cyclo-hexylbenzene oxidation and cleavage section  
   Section 300—p-Di-cyclohexylbenzene transalkylation  
   Section 400—Cyclo-hexane de-hydrogenation  
   Section 500—Phenol and cyclohexanone product recovery  
6 **Cost estimates**  
   Fixed capital costs  
   Production costs
Tables

Table 2.1 Exxon's three-step process for phenol production—Summary 10
Table 2.2 Exxon's three-step process comparison with other processes 12
Table 2.3 Exxon's three-step process for phenol production—Environmental footprint 13
Table 3.1 World top producers of phenol by shareholder—2017 14
Table 3.2 Worldwide phenol plant production capacities in -000s tons/annum for year 2019 15
Table 3.3 World supply/demand for phenol (thousands of metric tons) 18
Table 3.4 World consumption of phenol—2017 (thousands of metric tons) 19
Table 3.5 World top producers of (uncoupled) cyclohexanol/cyclohexanone—2018 (thousands of metric tons) 20
Table 4.1 Benzene hydroalkylation reactor typical product from patent US8329956 27
Table 5.1 Design basis and assumptions for Exxon's three-step process for phenol production 35
Table 5.2 Exxon's three-step process for phenol production—Major stream flows 42
Table 5.3 Exxon's three-step process for phenol production—Major equipment 52
Table 5.4 Exxon's three-step process for phenol production—Utilities summary 57
Table 5.5 Exxon's three-step process for phenol production—Total capital investment 59
Table 5.6 Exxon's three-step process for phenol production—Variable costs 60
Table 5.7 Exxon's three-step process for phenol production—Production cost 61

Figures

Figure 4.1 Benzene catalytic hydroalkylation reactors from patent EP2103585 27
Figure 4.2 Process scheme for benzene hydroalkylation to produce phenol from patent EP2189975 28
Figure 4.3 Overall process scheme to produce phenol and cyclohexanone from benzene from US4021490 31
Figure 4.4 Overall process scheme (part 1) to produce phenol and cyclohexanone from cyclohexylbenzene from WO2014/137623 32
Figure 4.5 Overall process scheme (part 2) to produce phenol and cyclohexanone from cyclohexylbenzene from WO2014/137623 32
Figure 5.1 Effect of benzene feed price on phenol product value 62
Figure 5.2 Effect of cyclohexanone by-product price on phenol product value 62
Figure 5.3 Effect of plant capacity on net production cost of phenol 63

Appendix C Figures

Figure 5.1 PFD 1 of 4: Benzene hydro de-alkylation and solvent extraction section 75
Figure 5.1 PFD 2 of 4: Cyclohexylbenzene oxidation and cleavage section 76
Figure 5.1 PFD 3 of 4: Poly-cyclohexylbenzene transalkylation section and cyclohexane dehydrogenation sections 77
Figure 5.1 PFD 4 of 4: Phenol and cyclohexanone product recovery section 78