

# Modelling and exergy analysis of the natural gas to hydrocarbon liquids (GTL) process

by

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# Synopsis

The interest in using Fischer–Tropsch synthesis for converting natural gas to liquids has increased during the last couple of years. Most of the technologies are well established individually, but integrating these technologies have not been applied and optimised widely. Firstly process integration was performed on a Gas-to-Liquids (GTL) process consisting of an autothermal reformer (ATR) and low temperature slurry bed reactor (SBR) with external recycling. Secondly the interactions of the integrated GTL process were investigated with specific focus on factors influencing the carbon efficiency. It was evident that a trade-off exists between carbon efficiency, methane slip and energy utilization. Exergy analysis was used as optimization tool and resulted in an optimum ATR temperature of 975°C. The results showed that at the optimum temperature the methane slip (2.7%) is still within an acceptable range. When comparing the optimum ATR temperature to a temperature of 1100°C, the improvement in carbon efficiency is 7% and the total exergy loss is 26% lower. At this optimum ATR temperature the energy is utilized in such a manner that the maximum exergy is stored in the final product (i.e. liquid hydrocarbons) and not in utilities (i.e. electricity) produced by the process.

## Keywords

Gas-to-Liquids, exergy, reforming, Fischer–Tropsch, process integration, carbon efficiency, process optimization

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# Nomenclature

$\dot{m}$	Mass flow rate of fluid stream, $kg/s$
$\dot{Q}_r$	Heat transfer rate, $W$
$\dot{W}_x$	Shaft power, $W$
$\dot{W}_{max}$	Maximum work, $W$
$\varepsilon^{\Delta P}$	Pressure dependent component of exergy streams with regards to physical exergy, $W$
$A$	Area for heat transfer, $m^2$
$C_0$	Bulk velocity of fluid stream relative to surface of earth, $m/s$
$g_E$	Gravitational acceleration, $kg/m \cdot s^2$
$H_0$	Enthalpy at $T_0$ , $kJ/mol$
$H_1$	Enthalpy at given state, $kJ/mol$
$I$	Irreversibility, $W$
$k_1$	Reaction constant for first FT reaction mechanism (Lox & Froment, 1993)
$k_5$	Reaction constant for fifth FT reaction mechanism (Lox & Froment, 1993)
$k_6$	Reaction constant for sixth FT reaction mechanism (Lox & Froment, 1993)
$n$	Carbon chain length
$p$	Alpha value
$P_0$	Reference pressure, $bar$

$Q$	Heat, $J$
$R$	Gas constant, $8.314 J/mol \cdot K$
$S_0$	Entropy at $T_0$ , $kJ/mol$
$S_1$	Entropy at given state, $kJ/mol \cdot K$
$T_0$	Ambient temperature; standard temperature, $K; ^\circ C$
$T_r$	Reactor/reaction temperature, $K; ^\circ C$
$T_{ref}$	Temperature of ATR, $K; ^\circ C$
$U$	Overall heat transfer coefficient. $W/m^2 \cdot K$ ; internal energy, $J$
$x_i$	Mole fraction of component $i$
$y_n$	Flory mole fraction distribution
$Z_0$	Altitude of stream above sea level, $m$
$C_p$	Heat capacity, $kJ/mol \cdot K$

### Subscripts

$0$	Chemical
$0$	Environmental state (reference state)
$E$	Related to energy
$i$	Related to component $i$
$k$	Related to kinetic energy
$m$	Mean
$max$	Maximum
$n$	Carbon chain length
$p$	At constant pressure
$p$	Related to potential energy

$ph$	Physical
$r$	Related to rate
$r$	Related to reaction
$ref$	Reformer
<b>Greek</b>	
$\alpha$	Schulz-Flory alpha distribution
$\Delta T_m$	Mean temperature - driving force for heat transfer, $K$
$\Delta$	Change: (out-in) or (end-beginning)
$\Delta_r G^0$	Standard Gibbs energy of reaction, $kJ/mol$
$\Delta_r H^0$	Standard heat of reaction, $kJ/mol$
$\dot{\epsilon}^{W_x}$	Exergy related to work, $W$
$\dot{\epsilon}_{in}, \dot{\epsilon}_{out}$	In and out going exergy material streams, $W$
$\dot{\epsilon}$	Exergy of a stream of matter, $W$
$\dot{\epsilon}^Q$	Thermal exergy, $W$
$\dot{\epsilon}_0$	Chemical exergy, $W$
$\dot{\epsilon}_k$	Kinetic exergy, $W$
$\dot{\epsilon}_p$	Potential exergy, $W$
$\dot{\epsilon}_{ph}$	Physical exergy, $W$
$\Pi$	Entropy production, $kJ/K \cdot s$
$\tau$	Carnot factor
$\epsilon^{\Delta T}$	Temperature dependent component of exergy streams with regards to physical exergy, $W$
$\epsilon_0$	Standard chemical exergy of component i, $W$

## Superscripts

$P$	Dependent on pressure
$Q$	Related to heat
$T$	Dependent on temperature
$W_x$	Related to work

## Abbreviations

ATR	Autothermal reformer
FT	Fischer-Tropsch
GTL	Gas-to-Liquids
HTFT	High temperature Fischer-Tropsch
LTFT	Low temperature Fischer-Tropsch
POX	Partial oxidation
SBR	Slurry bed reactor
SMR	Steam methane reforming
SSBR	Sasol Slurry Bed Reactor
syngas	Synthetic gas
TFBR	Tubular fixed bed reactor