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Simulation of energy reduction in CO_2 absorption using split-stream configuration

by

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BACKGROUND

- **At Telemark University College, Aspen HYSYS has been used for simulation of CO_2 removal from atmospheric exhaust by absorption in amine. The process has been cost estimated and optimized.**

- **Lars Erik Øi is Master in Chemical Engineering from NTNU in Trondheim and is Associate Professor and PhD student in CO_2 removal.**

- **Vladyslav Shchuchenko is Bachelor in Mechanical Engineering from NTUU ”KPI” in Kiev, and Master in Process Technology (2011) from Telemark.**

OUTLINE

- **The most standard method for CO_2 removal from atmospheric exhaust is by absorption in an amine based solution (MEA = MonoEthanolAmine).**
- **The desorption (stripping of CO_2 from the amine) has a high thermal energy demand (4.2 MJ/kg CO_2).**
- **This energy can be reduced by changing the process stream configuration (e.g. split-stream or vapour recompression).**
- **What is the potential in energy reduction?**
- **Is split-stream a cost efficient solution?**

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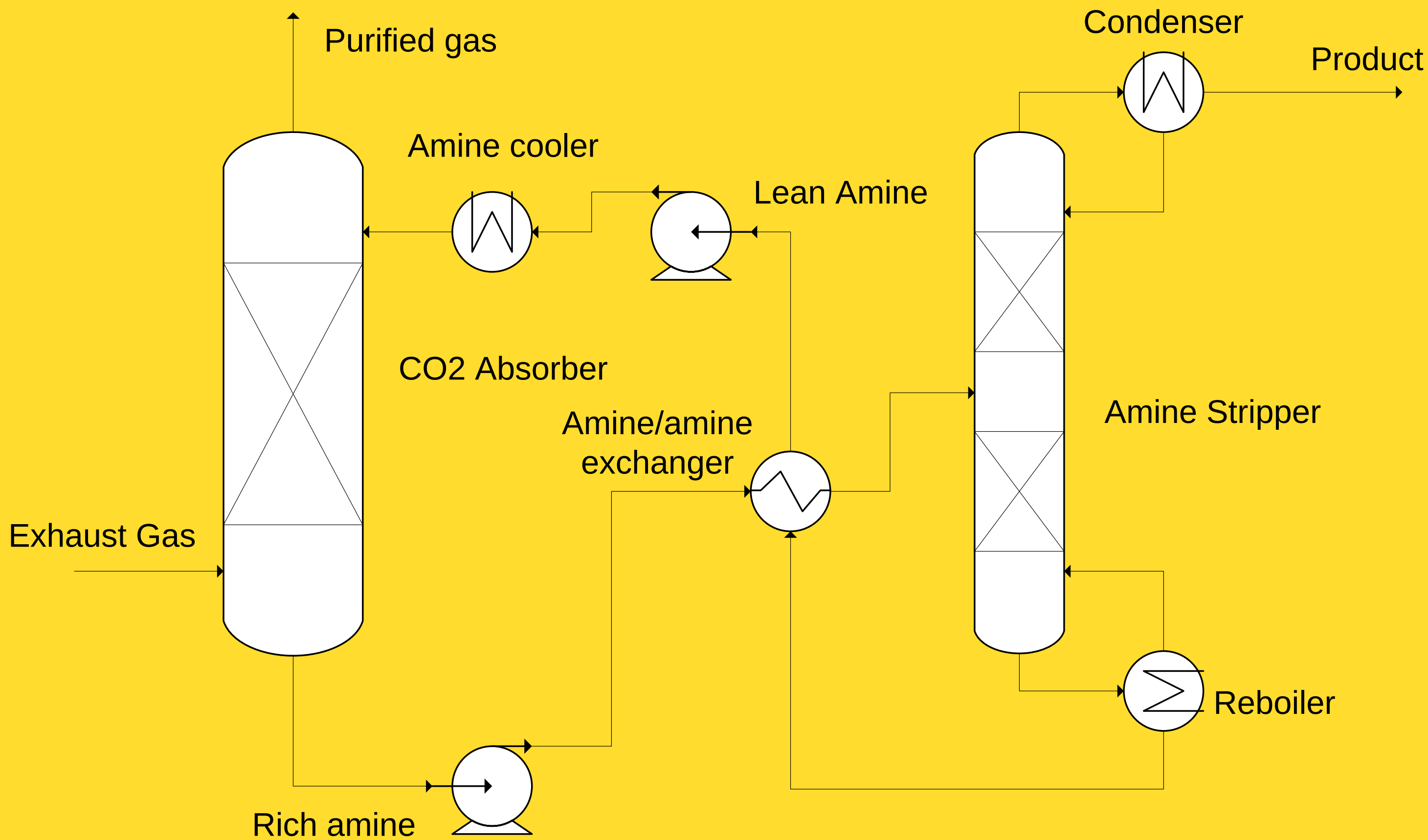
FLOWSHEET FOR STANDARD PROCESS



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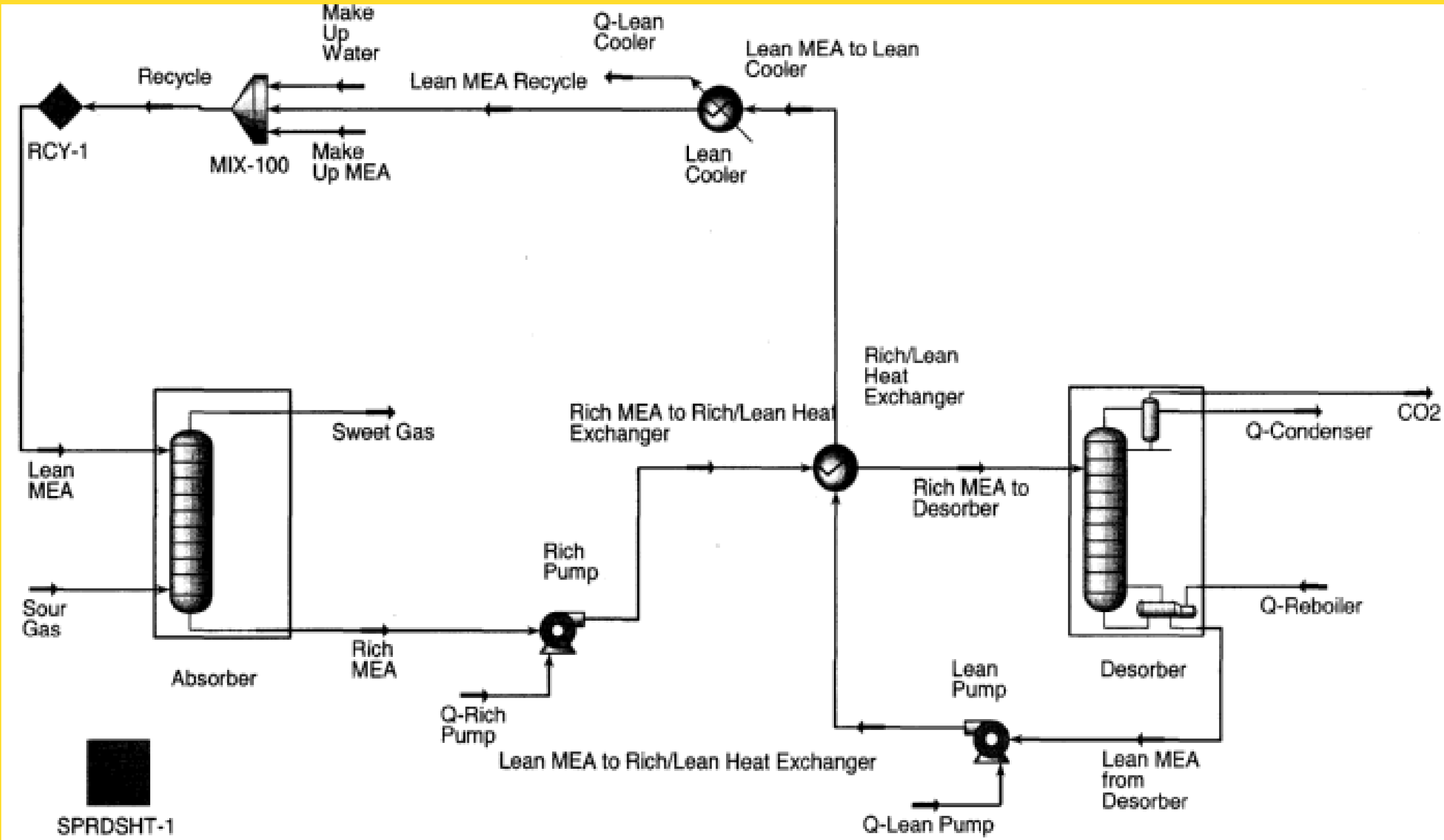
Aspen HYSYS FLOWSHEET STANDARD CO_2 REMOVAL



PROCESS SIMULATION

Simulation of CO_2 removal has been performed with

- **Aspen HYSYS amine package with Kent Eisenberg equilibrium model.**

Typical specifications for exhaust gas from a natural gas based combi-cycle power plant:

- **400 MW**
- **3.71 % CO_2 in exhaust gas**
- **85 % CO_2 removal**

Monoethanol amine (MEA, 30 wt-%) as solvent

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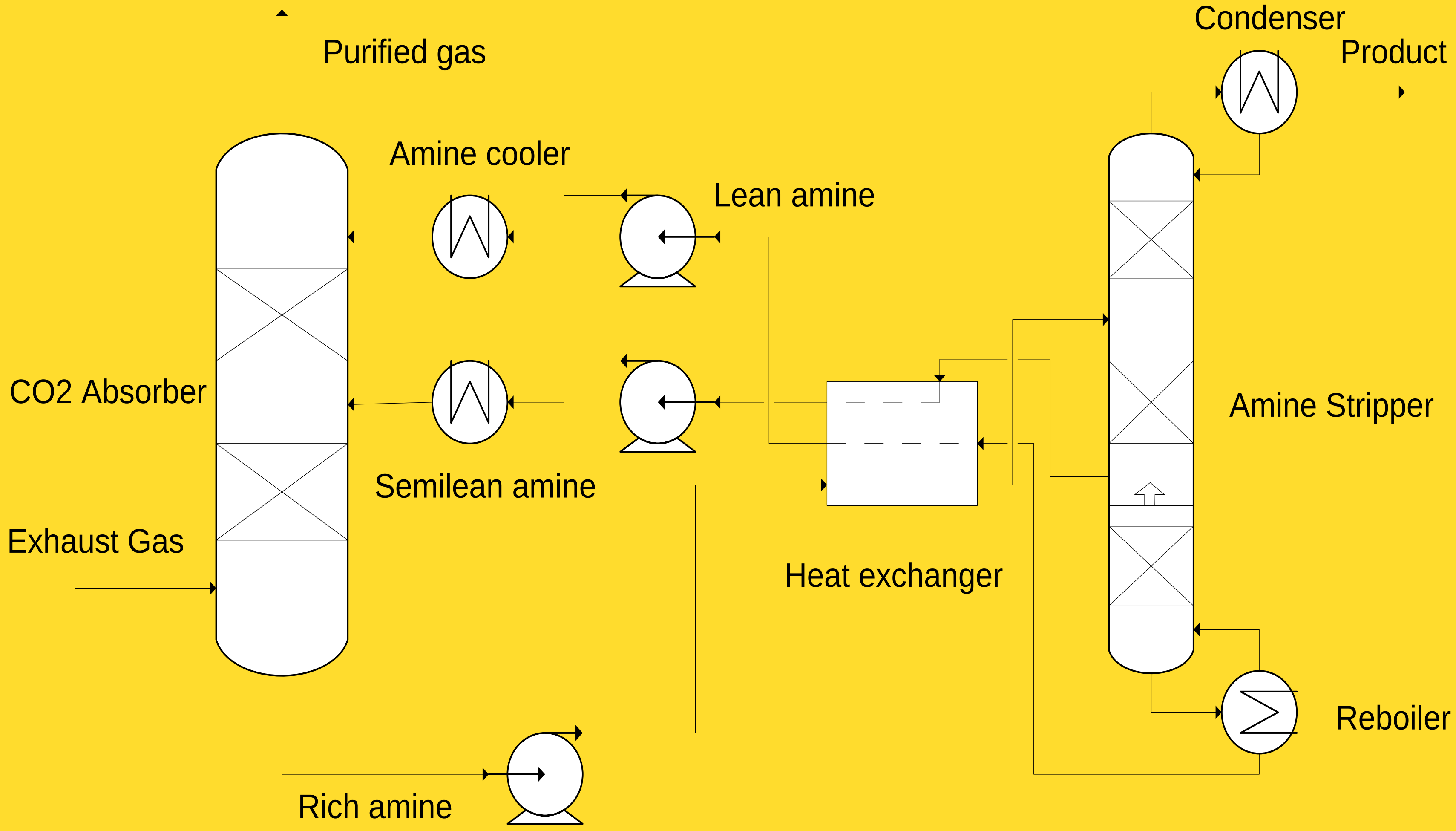
FLOWSHEET FOR SPLIT-STREAM PROCESS



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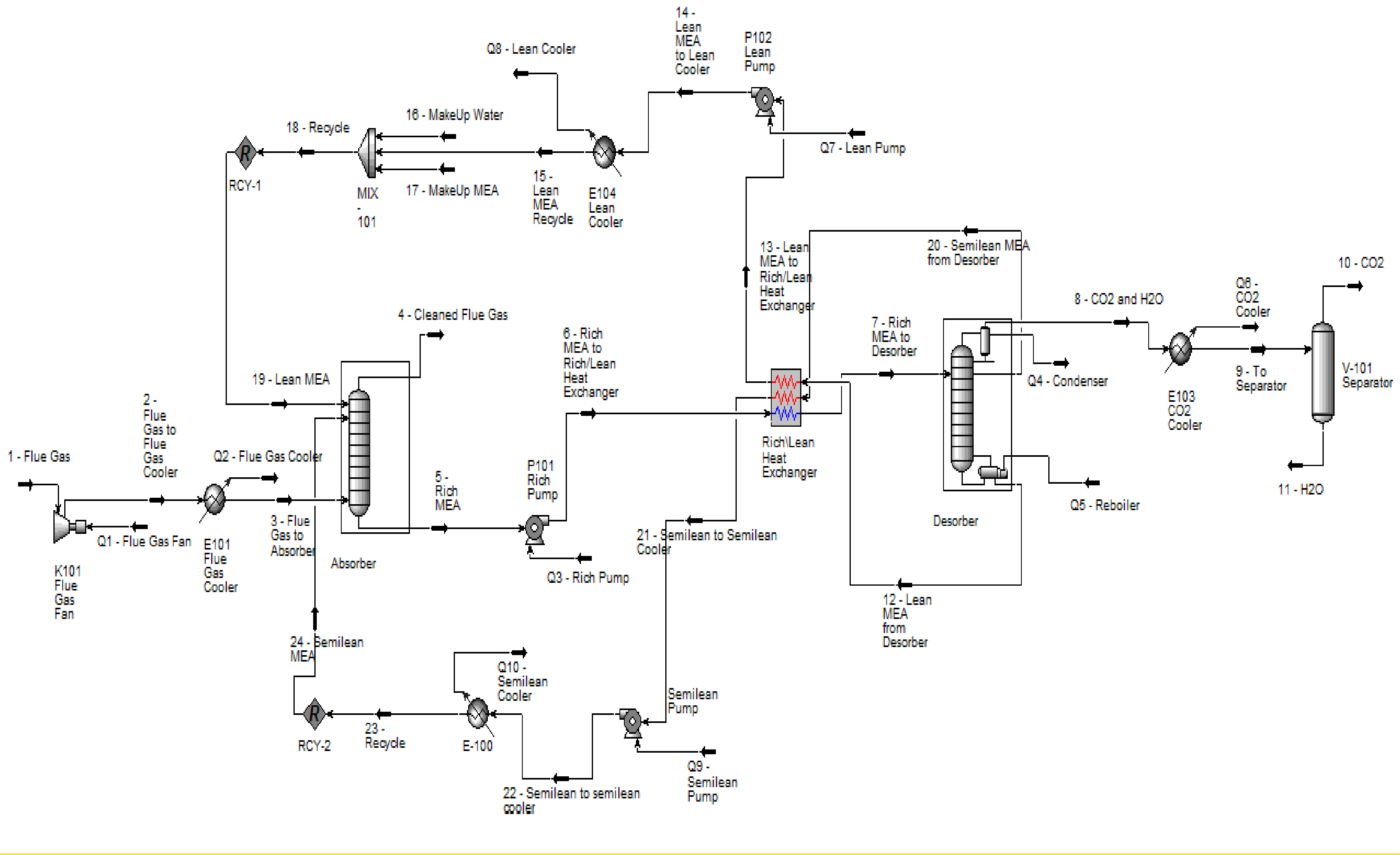
SPECIFICATIONS

Specifications	Without split-stream	With split-stream
Inlet gas temperature, °C	40	40
Inlet gas pressure, bar	1,11	1,11
Inlet gas flow, kgmole/h	110000	110000
Lean amine rate, kgmole/h	165000	103500
CO_2 in inlet gas, mole-%	3,7	3,7
CO_2 in lean amine, mass-%	5,5	5,5
Number of stages in absorber	14 (15 % $E_{MURPHREE}$)	24 (semilean to 21)
Desorber pressure, bar	2	2
Heated rich amine temperature, °C	104,2	96,6
Number of stages in stripper	10+Condenser+Reboiler	6+Condenser+Reboiler
Reboiler temperature, °C	120	120
Semilean amine rate, kgmole/h	-	100000
MEA content lean/semilean amine, mass-%	29	29/28
CO_2 in semilean amine, mass-%	-	9,0

Aspen HYSYS FLOWSHEET FOR SPLIT-STREAM



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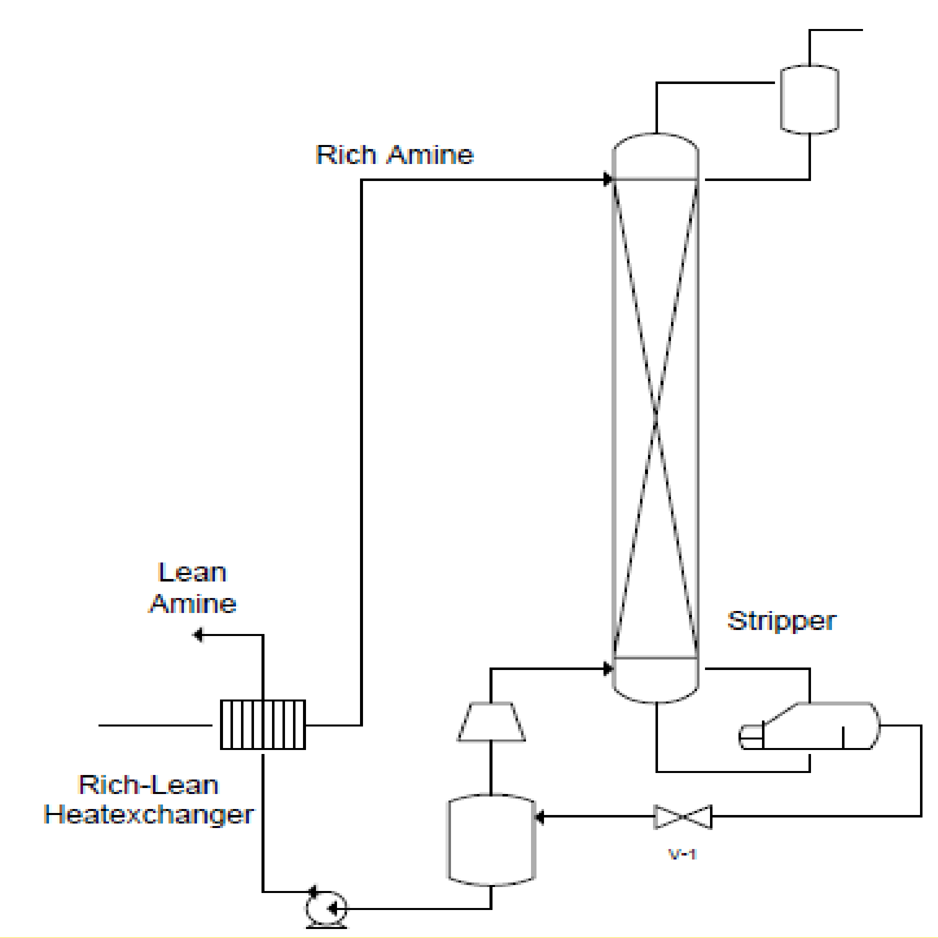
PRINCIPLE FOR VAPOUR RECOMPRESSION MODIFICATION



From Karimi et al. (2010)

After the reboiler, the lean amine is deprezzurized. The vapour is comressed and returned to the stripper.

EARLIER RESULTS

• In earlier work (at Telemark University College and in the literature) it has been shown that the heat demand can be reduced from about 4.2 MJ/kg CO_2 .

• to 3.0 MJ/kg CO_2 using split-stream configuration.

• to 2.6 MJ/kg CO_2 using vapour recompression with addition of mechanical work for recompression.

Results from simulations of a combination of vapour recompression and split-stream have not been published earlier.

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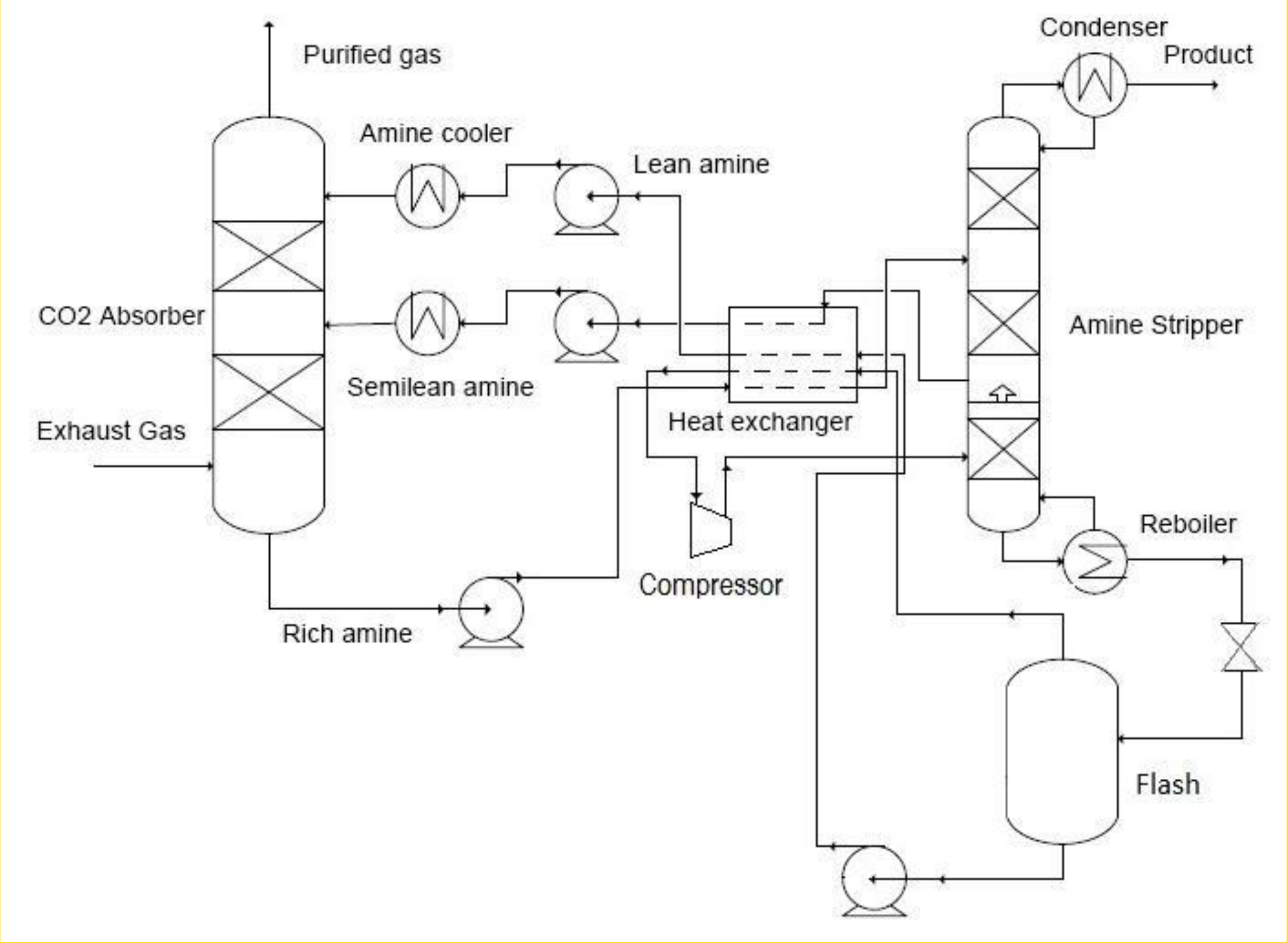
VAPOUR RECOMPRESSION COMBINED WITH SPLIT-STREAM CONFIGURATION



CALCULATION SEQUENCE

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- The number of stages in the absorber was increased until problems with convergence occured. This is expected to minimize the reboiler duty. The feed stage for the semi-lean stream was also selected as the one giving minimum reboiler duty.

- A minimum temperature difference of 5 K in the heat exchangers was achieved by adjusting the temperature on the stream to the desorber.

- Recycle blocks are located on lean amine streams before the absorption column and on the recompression stream before the desorber column. In some cases, the iterations were performed by guessing tear streams by trial and error until the difference in CO_2 concentration was satisfactory.

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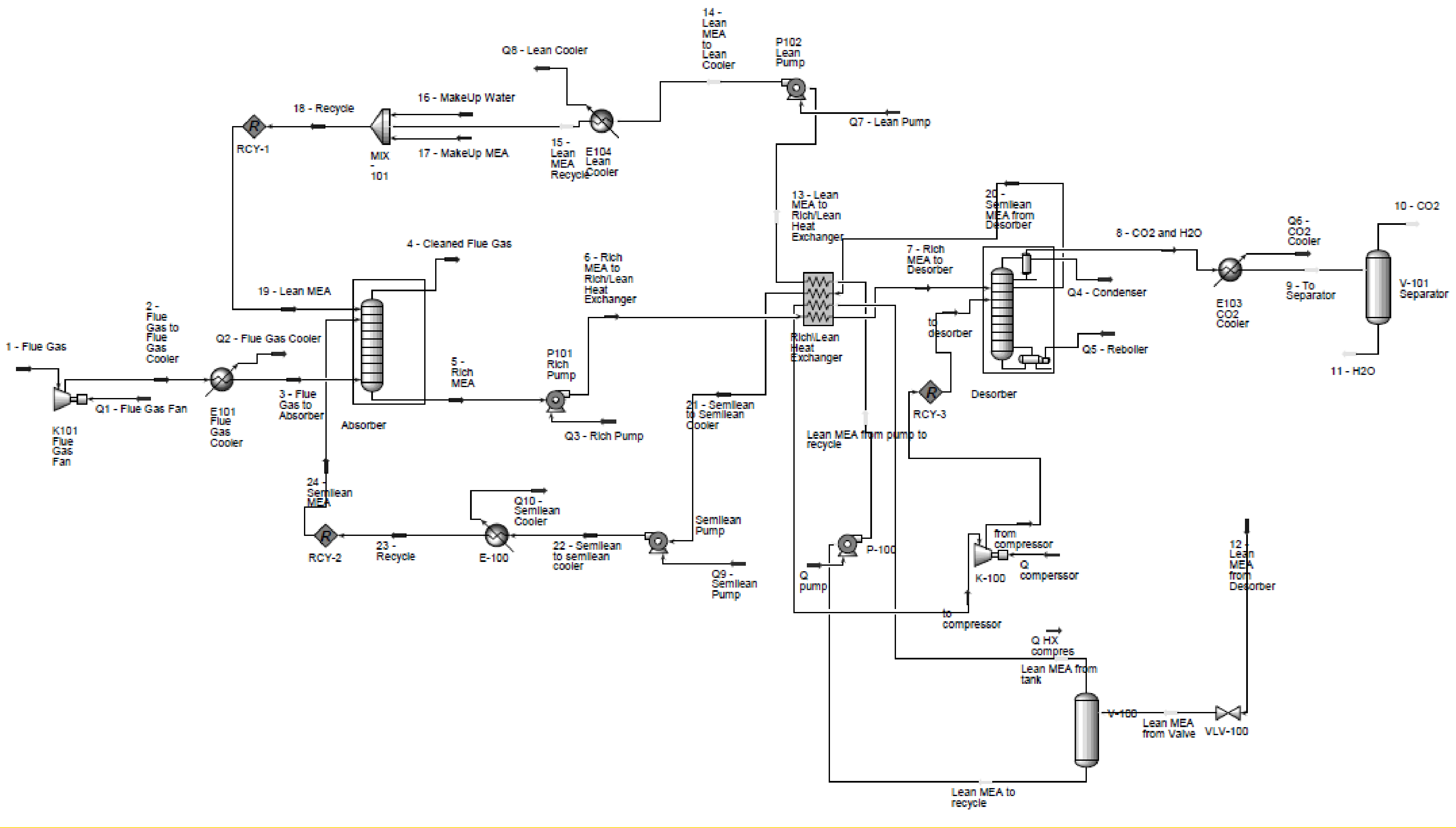
ASPEN HYSYS FLOWSHEET OF VAPOUR RECOMPRESSION WITH SPLIT-STREAM FROM THE MIDDLE OF THE DESORBER



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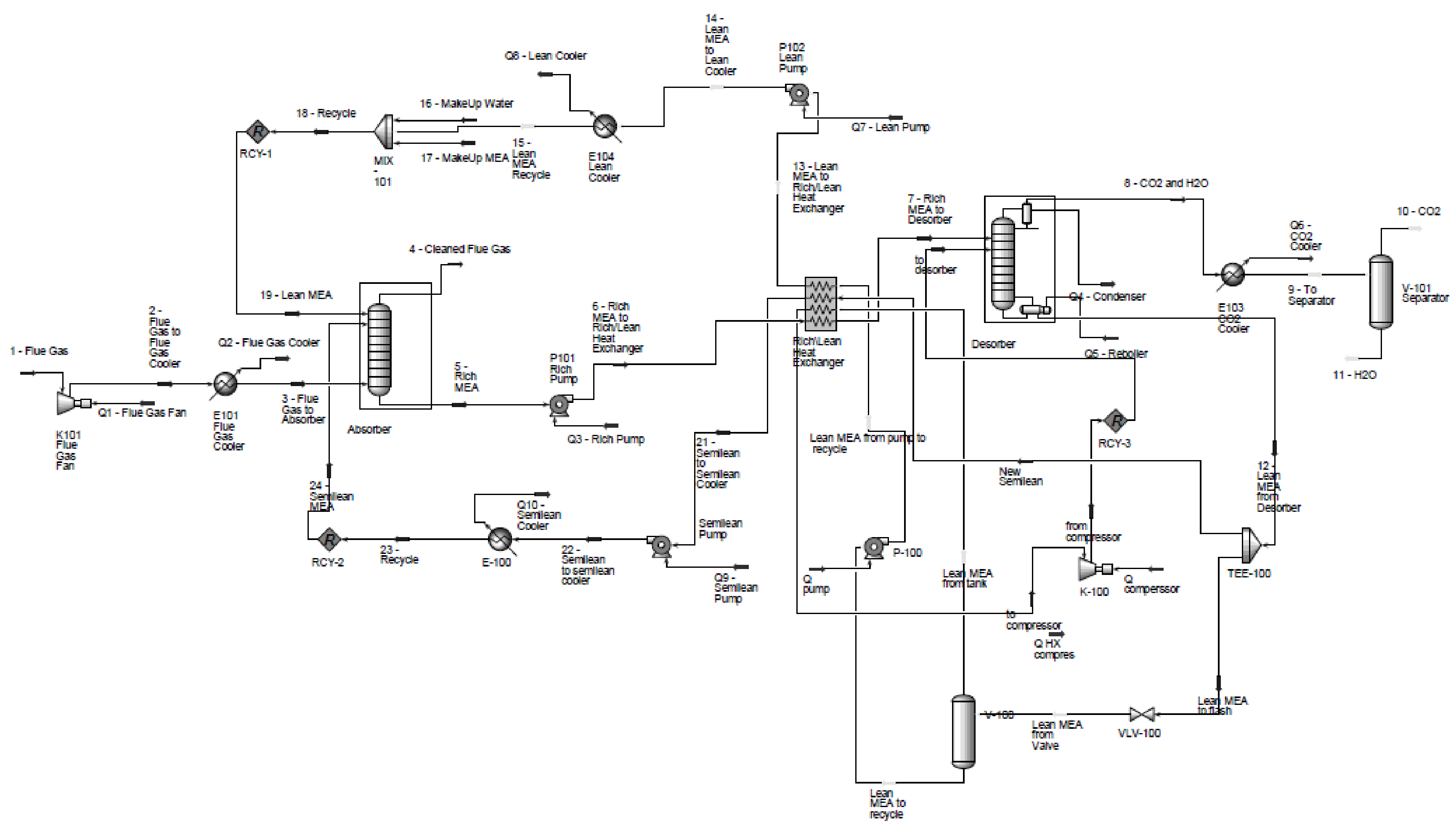
ASPEN HYSYS FLOWSHEET OF VAPOUR RECOMPRESSION WITH SPLIT-STREAM FROM THE BOTTOM OF THE DESORBER



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ASPEN HYSYS RESULTS FROM DIFFERENT CONFIGURATIONS

	Reboiler Duty [MJ/kg CO2]		Compressor duty, [MW]	
Base case CO_2 removal	**4.23**		**0**	
Split-stream configuration	**3.04**		**0**	
Standard vapour recompression	**2.64**		**3.9**	
Vapour recompression with split-stream from the middle of the desorber	**2.59**		**2.8**	
Vapour recompression with split-stream from the bottom of the desorber	**2.45**		**1.2**	

SPECIFICATIONS FOR ECONOMIC EVALUATIONS

Cost of electricity (mechanical work):

- **0.05 EURO/kWh**

Cost of steam (heat to reboiler):

- **0.013 EURO/kWh**

The ratio between electricity and steam cost is about 4. This is reasonable in a steam based power plant with a conversion efficiency from steam to electricity of about 25 %.

TOTAL ENERGY COST WITH DIFFERENT CONFIGURATIONS

	Heat/Work [MJ/kg CO2] /[MW]	Total energy cost [MEURO/yr]
Base case CO_2 removal	4.23/0.0	18.54
Split-stream configuration	3.04/0.0	13.56
Standard vapour recompression	2.64/3.9	13.15
Vapour recompression with split-stream from the middle of the desorber	2.59/2.8	12.46
Vapour recompression with split-stream from the bottom of the desorber	2.45/1.2	11.15

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EVALUATION OF THE RESULTING ENERGY CONSUMPTIONS IN THE DIFFERENT CONFIGURATIONS

Taking into account only energy consumption by the process, the vapor recompression modification with split-stream from the bottom of the desorber is the most efficient.

Considering also increased complexity and capital cost of the removal plant the vapor recompression configuration seems to be the best solution.

There is however a potential for improvements by further optimization of the process.

FURTHER OPTIMIZATION

Only some examples of split-stream configurations with vapour recompression has been evaluated.

Parameters like the ratio between lean and semi-lean flow-rate and the semi-lean removal stage from the desorber can be further optimized.

The economical comparison is sensitive to the large uncertainties in the cost estimates. Especially the energy cost is critical.

SUMMARY

A standard amine based CO_2 removal process and some split-stream and vapour recompression configurations have been simulated in Aspen HYSYS.

With 85 % CO_2 removal, it is possible to achieve an energy consumption of 2.5 MJ/kg CO_2 when using a combination of split-stream and vapour recompression.

Capital cost is higher for the complex split-stream processes. The complex split-stream alternatives becomes more attractive when energy cost increases.

The End