GRAN SASSO SCIENCE INSTITUTE

DARKSIDE

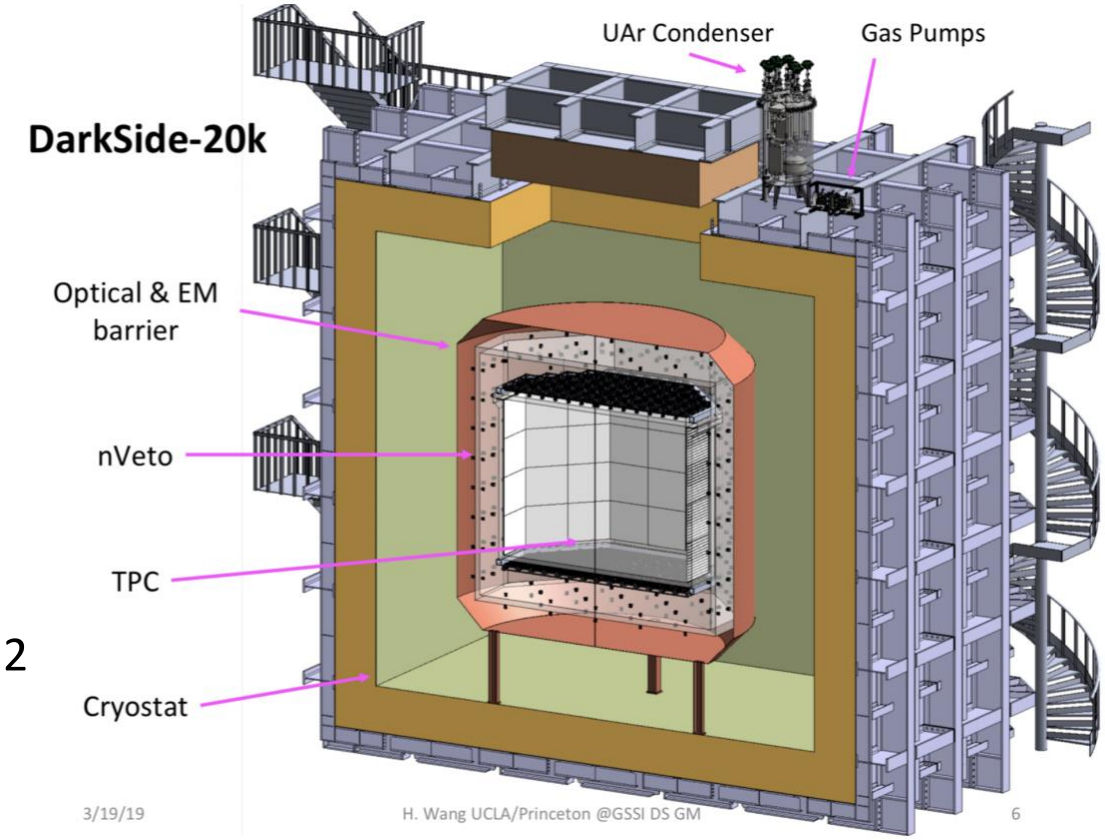
Argon distillation with the Aria project for dark matter searches

Supervisors
Prof. Cristian Galbiati, Dr. Walter Bonivento

Teena Vallivilayil John

DarkSide-20k

- WIMP Dark Matter search
- Dual-phase Liquid Argon TPC
- Two features
  - UAr as the WIMP target
  - SiPM-based Photodetector Modules (PDM) arrays as read-out
- DarkSide-20k needs 50 tons of UAr
- Projected sensitivity of 10^{-47} cm^2 for 1 TeV/c^2 WIMP mass.

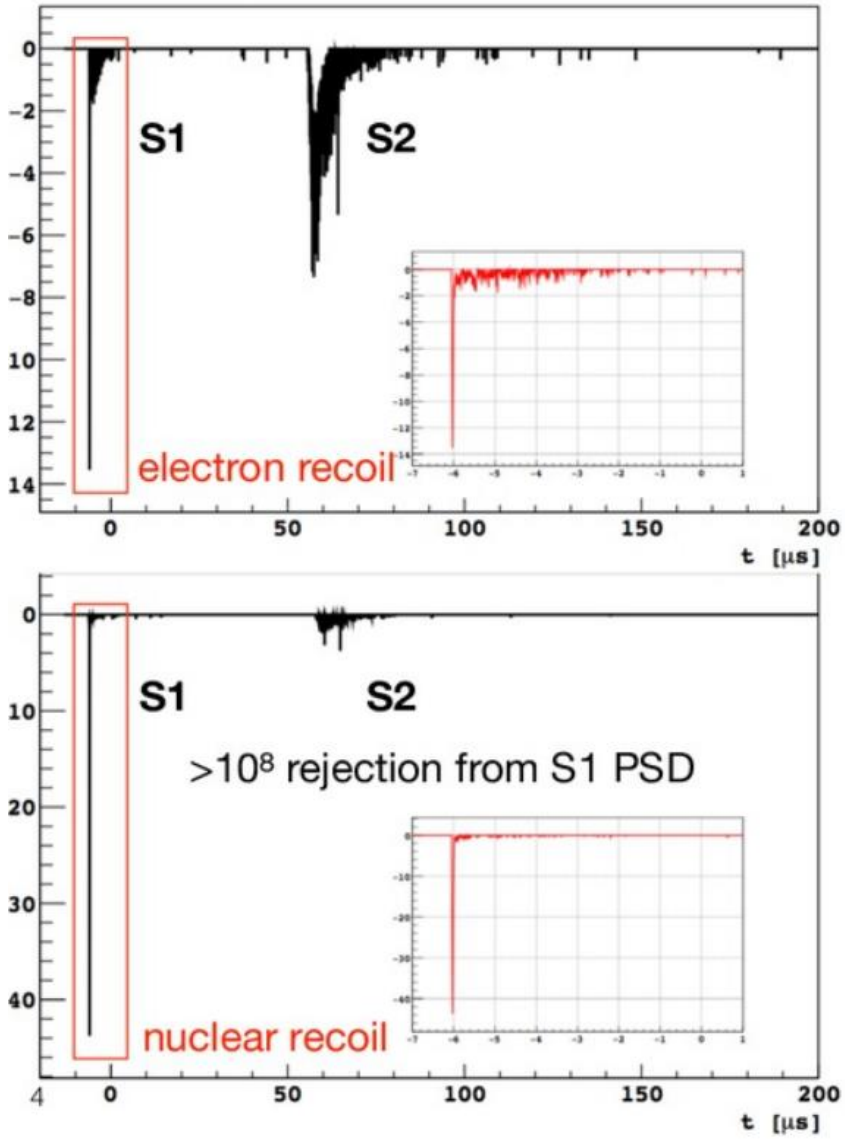


Liquid Argon

- Has high ionization and scintillation yields

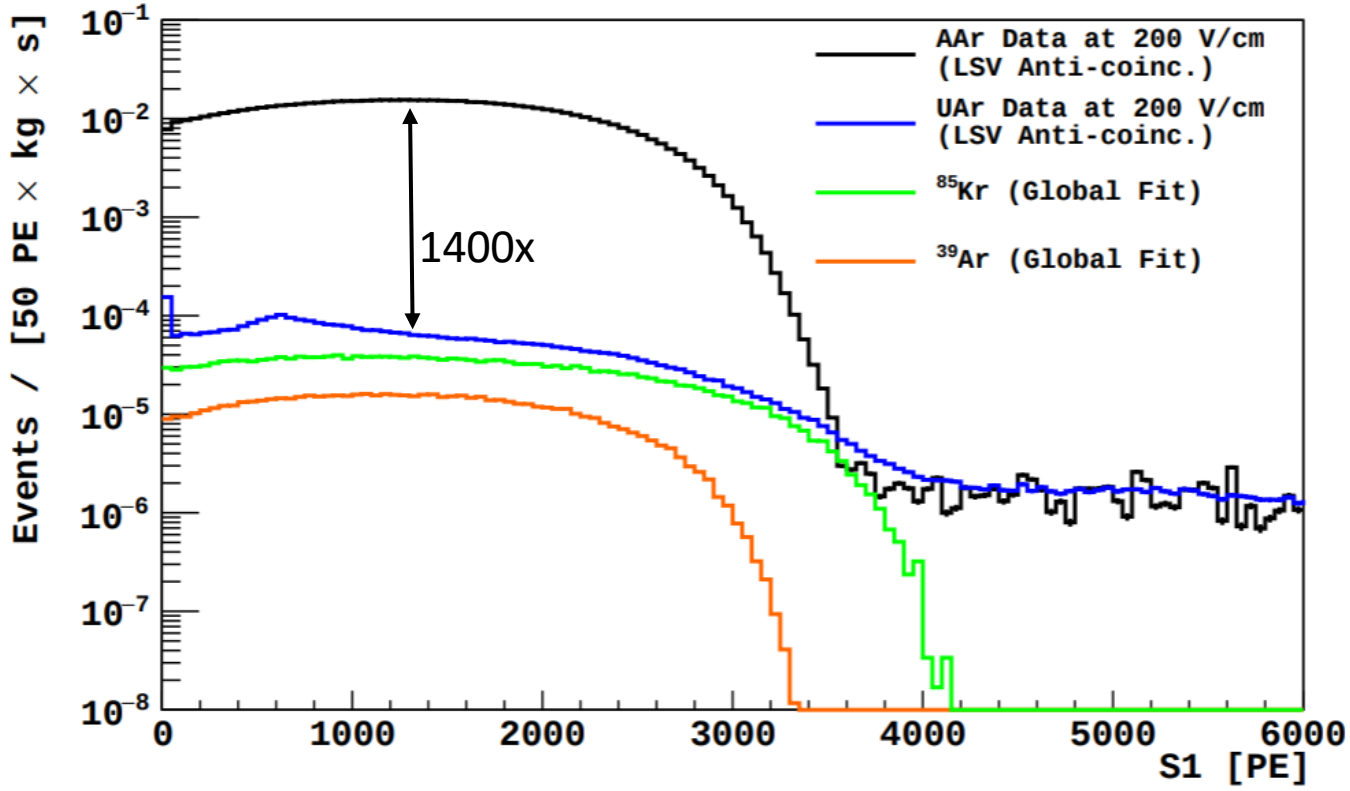
- Background rejection
  - Pulse shape Discrimination (PSD)
    - Fast decay time (Singlet) ~ 7 ns
    - Slow decay time (Triplet) ~ 1600 ns
    - Rejection power-10^8

- Main background-> ^{39}Ar
  - Produced primarily due to the cosmic ray interaction of ^{40}Ar.
  - Create a signal pile up as well as high data acquisition rates in the rare event search experiments.



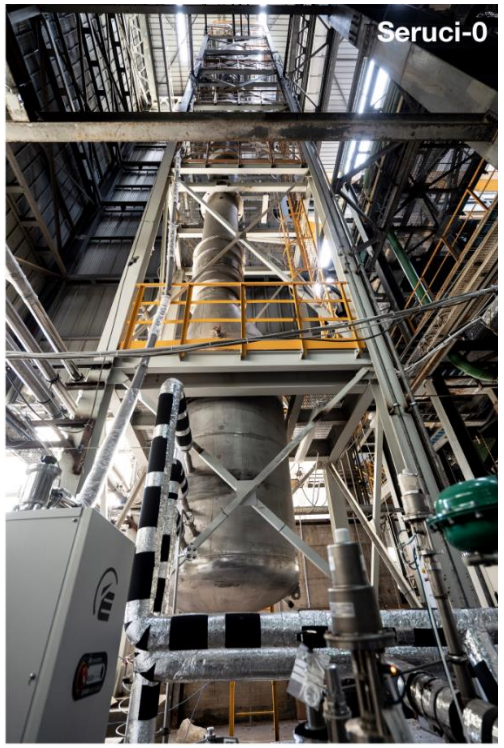
DS-50 Results

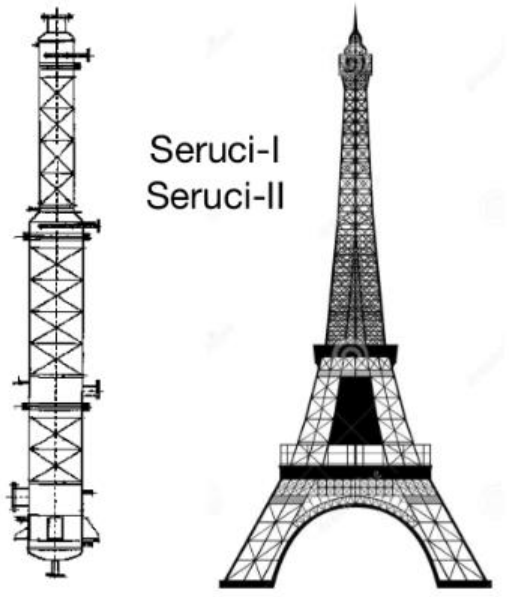
- The DS-50 collaboration has showed that underground Argon (UAr) from CO_2 well in Colorado has an ^{39}Ar rate of 7.3×10^{-4} Bq/kg.



ARIA

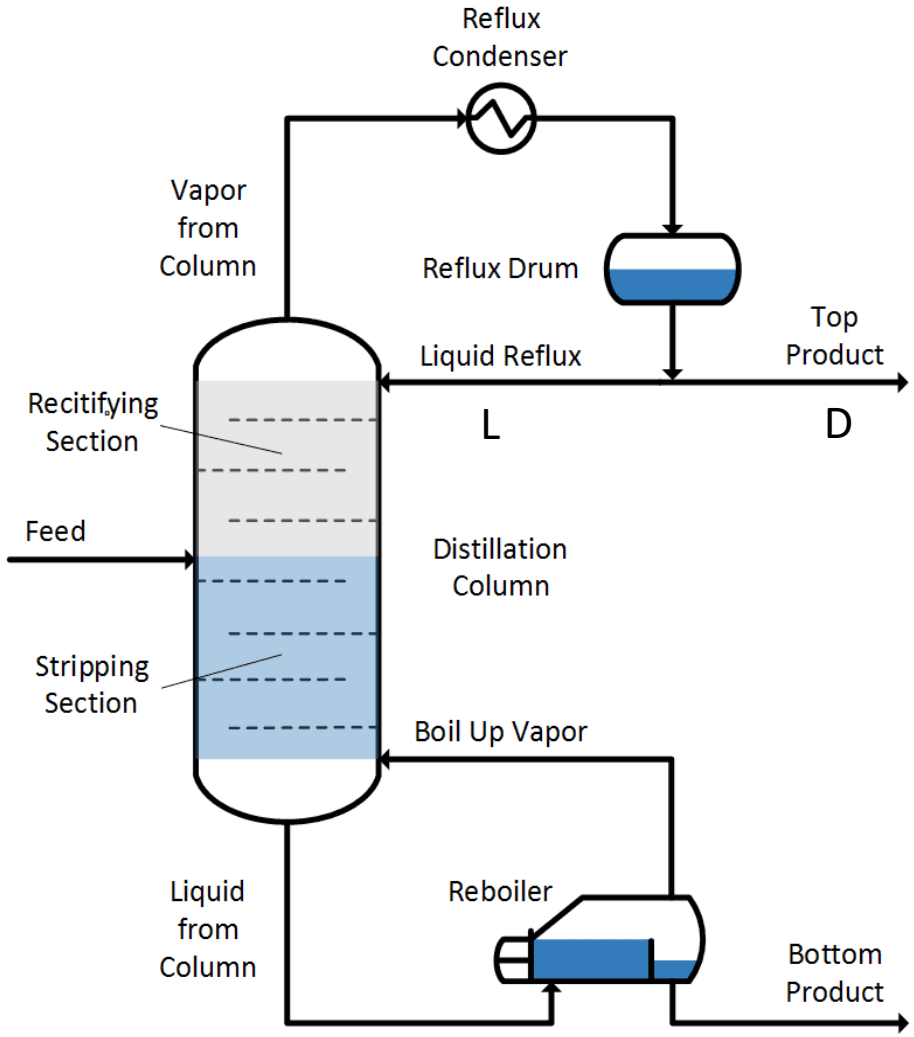
- Cryogenic isotopic distillation plant installed in a mine shaft at CarboSulcis, S.p.A. in Cagliari, Italy.
- 350m tall distillation column
- Designed to reduce ^{39}Ar isotopic fraction in UAr by a factor of 10 per pass.
- Production rate of 10 -15 kg/day
- Prototype Seruci-0 is assembled and a functionality test is done with nitrogen.





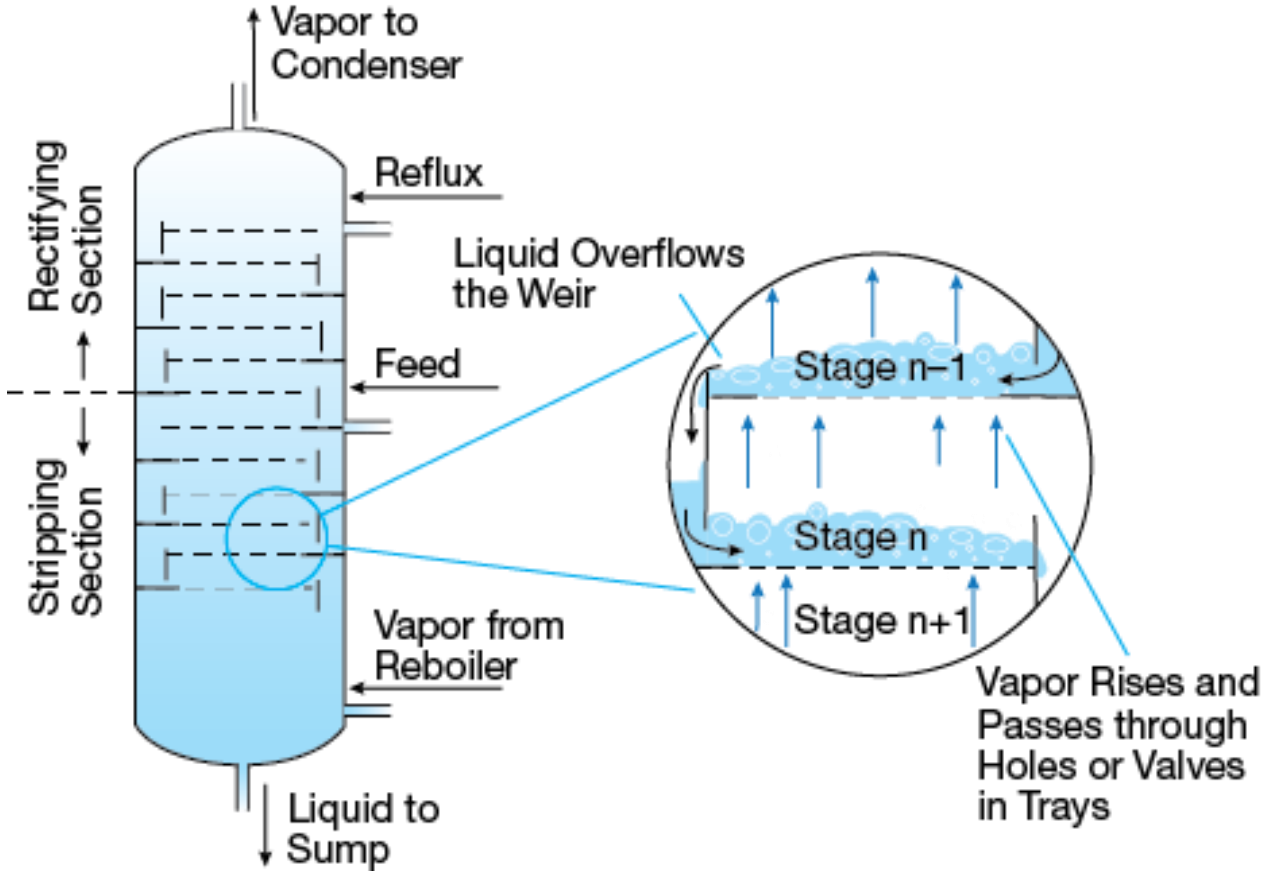
Distillation

- Physical separation process based on the volatility differences of the components in the liquid mixture.
- Relative volatility is the ratio between the volatility of the components in a mixture.
- The product purity in a distillation column is maximised by two methods: Refluxing and Reboiler
- Reflux ratio is defined as the ratio between liquid reflux (L) and top product (D).

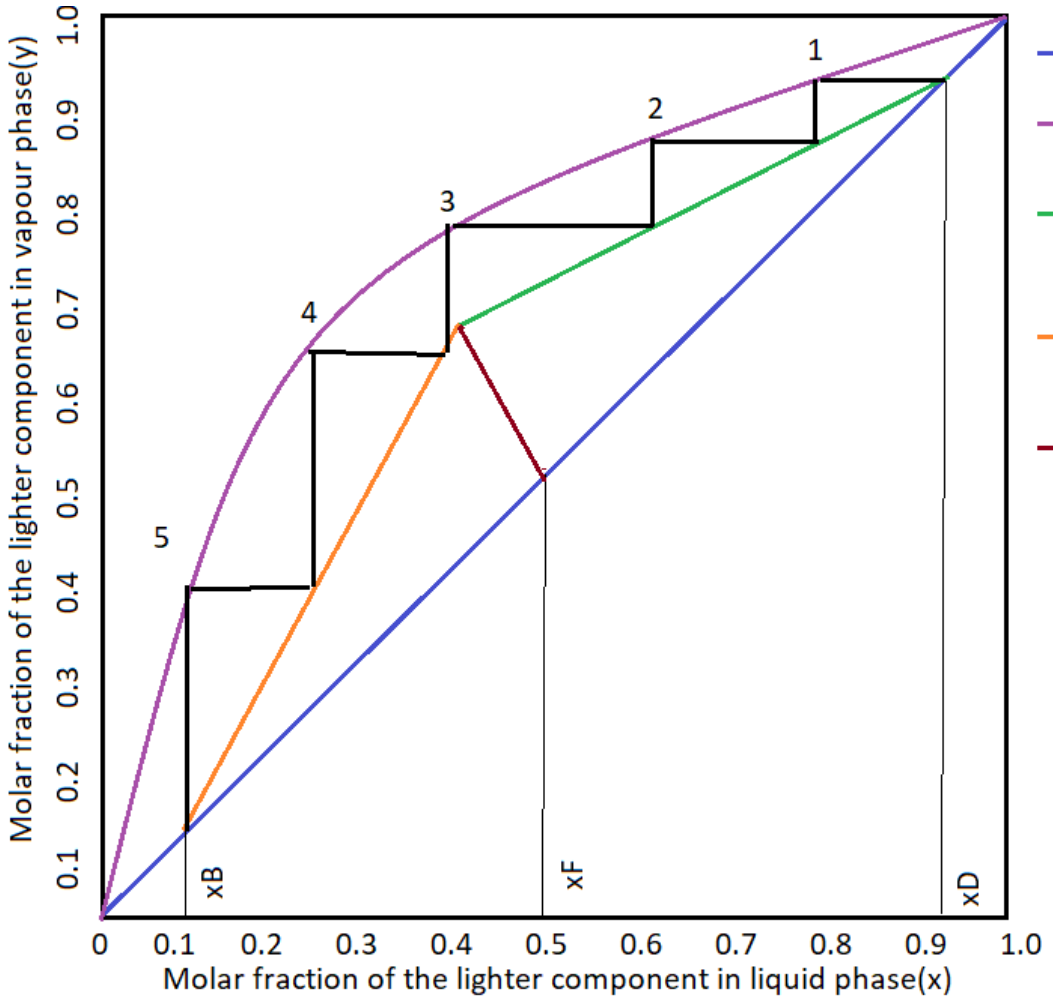


Distillation

- The vapour rises and liquid flows down in the distillation column.
- The distillation column contains trays or packings which are used to enhance the separation of the components in the liquid mixture.
- The vaporization-condensation cycle is the distillation cycle.
- As the relative volatility goes to unity, more distillation cycles are needed.



McCabe-Thiele Method

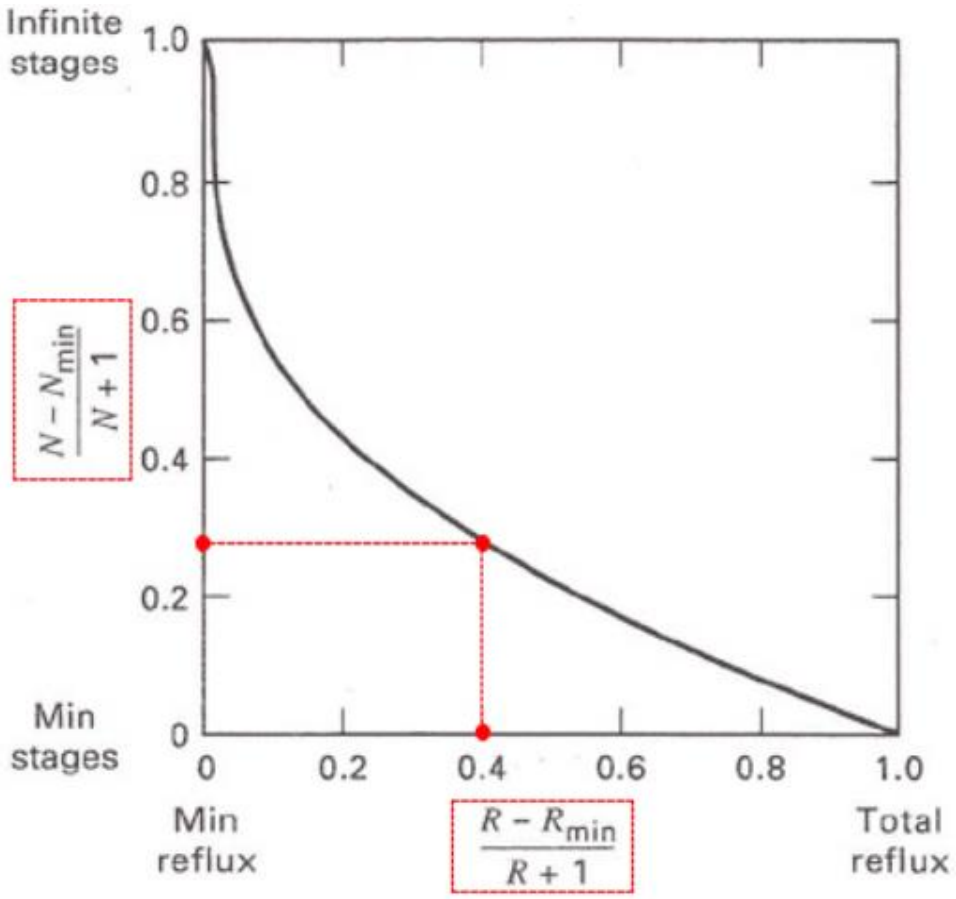


- A graphical method.
- Suitable for binary distillation

- x_D: Molar fraction of the lighter component in liquid phase at distillate.
- x_F: Molar fraction of the lighter component in liquid phase at feed.
- x_B: Molar fraction of the lighter component in liquid phase at bottom.

Fenske-Underwood-Gilliland (FUG) method

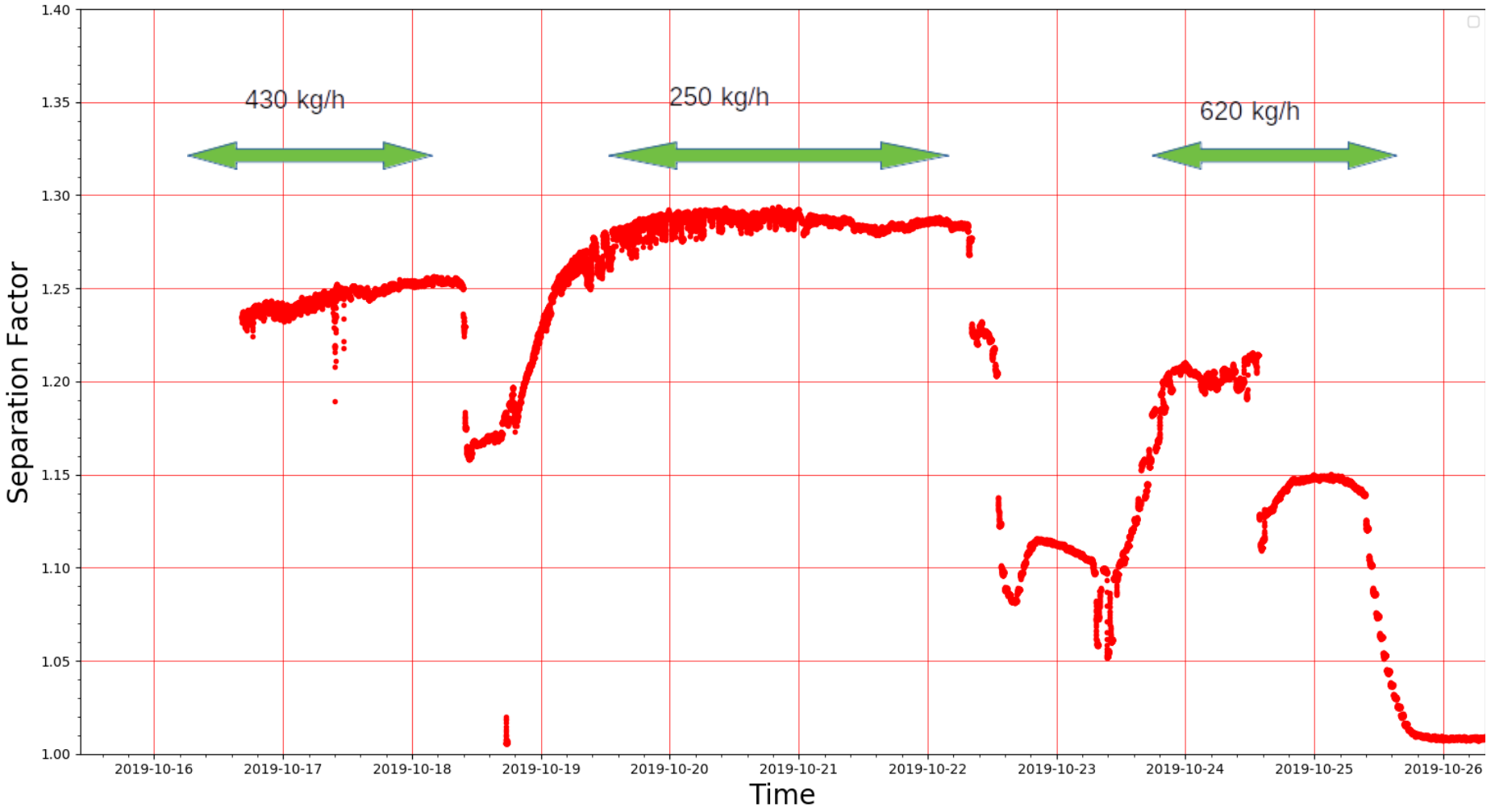
- Determination of the minimum number of stages at infinite reflux using Fenske equation.
- Calculation of the minimum reflux ratio using Underwood equation.
- Applying Gilliland Correlation, an engineering approximation, to determine the actual number of stages.



Commissioning run of the column

- Different compressor mass flows lead to different heat exchange rates in the “reboiler” and in the “condenser”.
- This implies different flow speeds in the distillation column, and it can lead to a different column distillation capability.
- The three different compressor configurations are used.
  - 430 kg/h
  - 250 kg/h
  - 620 kg/h

Separation factor in three different compressor conditions



$$S = \frac{x_{LKT} / x_{HKT}}{x_{LKB} / x_{HKB}} = \frac{x_{LKT}\, x_{HKB}}{x_{HKT}\, x_{LKB}}$$

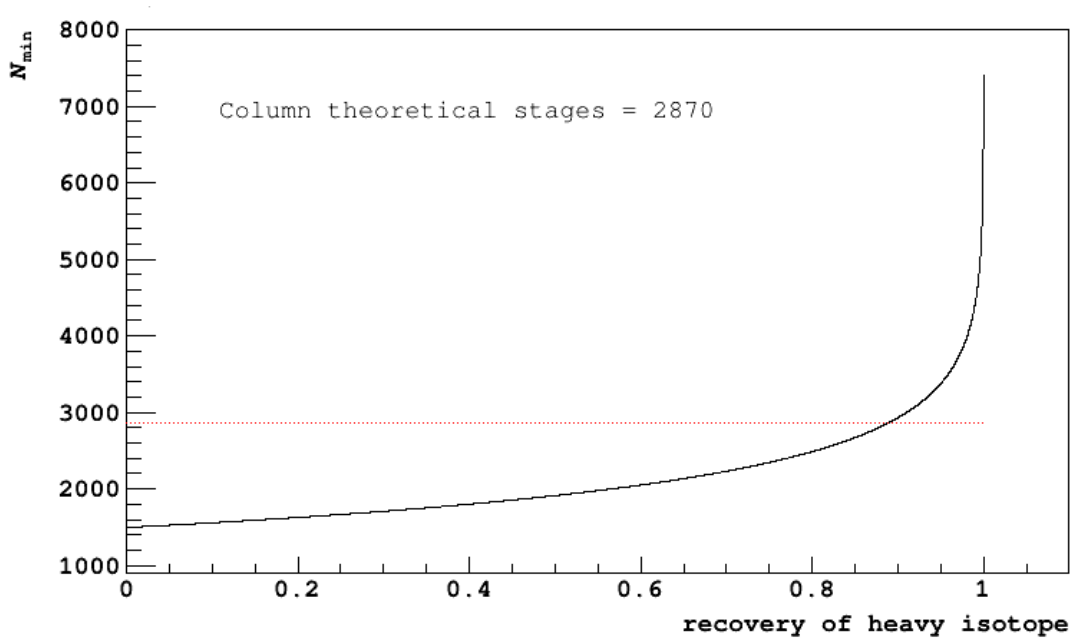
- LKT, LKB: Light key at Top & Bottom
- HKT, HKB: Heavy key at Top & Bottom

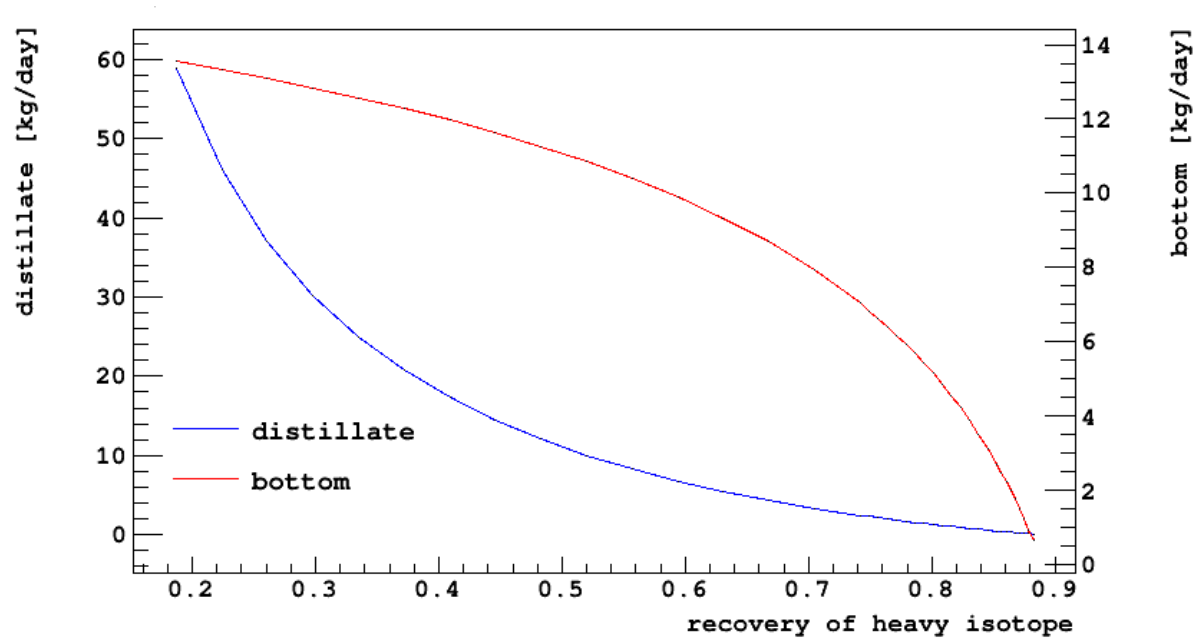
LK: ^{28}N
HK: ^{29}N

Solving McCabe Method by an Analytical Approach

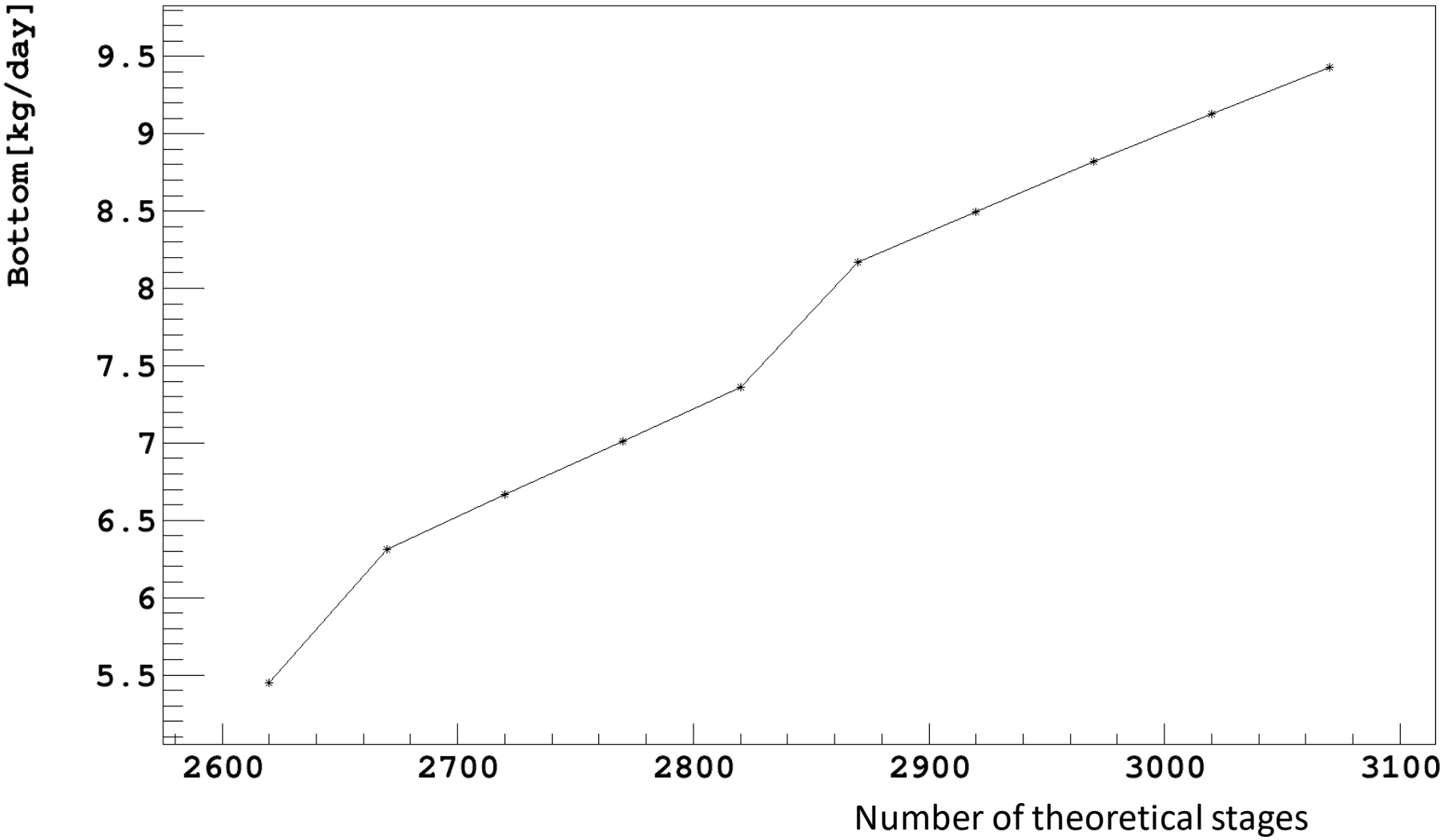
$x_D = 1.6 * 10^{-17}$

$x_F = 1.6 * 10^{-16}$





Production rate for different number of theoretical stages(McCabe method)

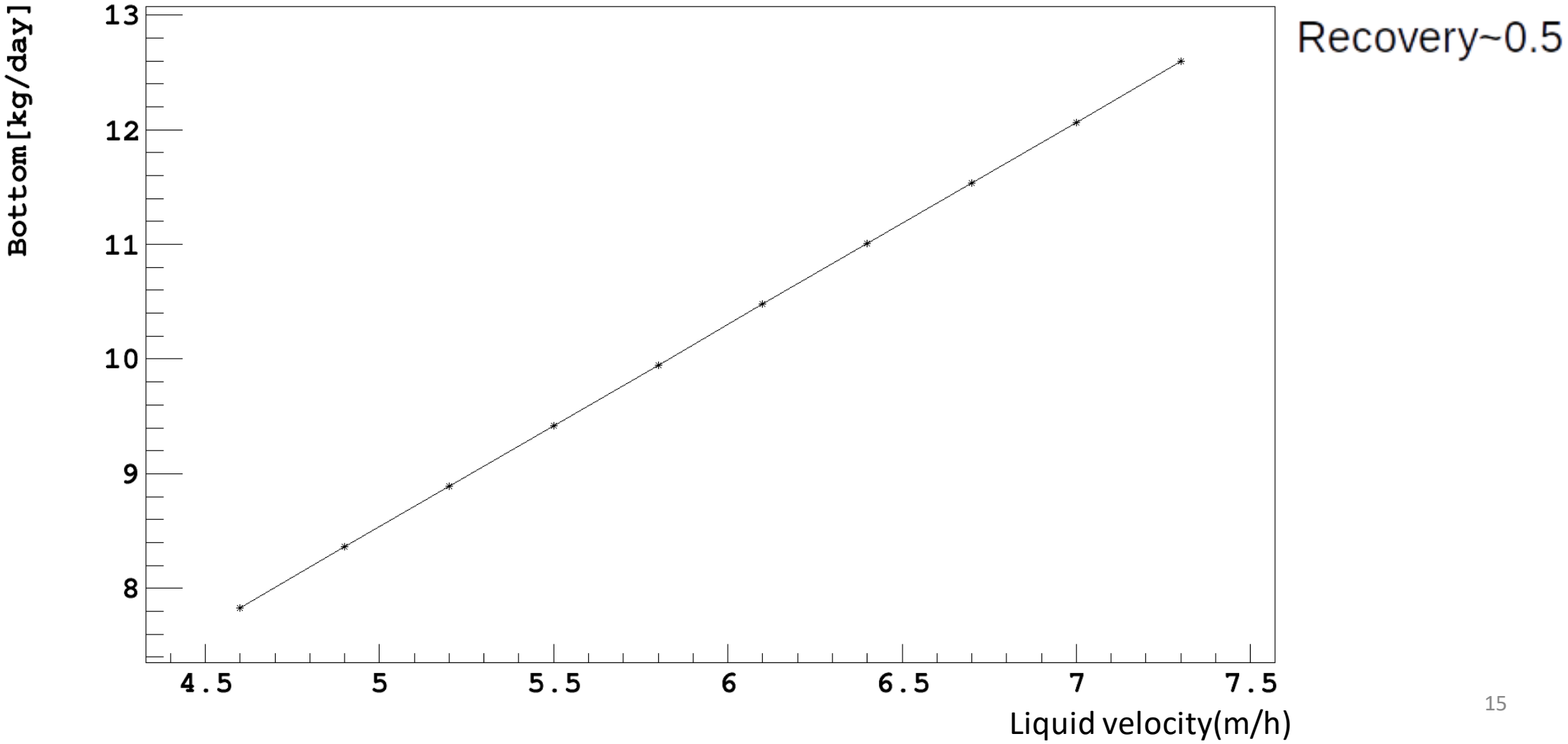


Recovery~0.5

Production rate for changing liquid density (McCabe method)

Recovery~0.5

Production rate for changing maximum liquid velocity (McCabe method)



Conclusion

- From the commissioning run data, the separation factor is calculated. The separation factor decreases with the increase in the mass flow in Compressor.

- The analytical approach of Mc-Cabe method and FUG method made the simulation working for Argon isotopes.

- The optimal values of liquid density, maximum liquid velocity, and the number of theoretical stages of distillation are found.

Future Plans

- Develop a simulation capable of multicomponent distillation which will help us to understand the dynamic behaviour of the distillation column and the controlling parameters better.

- Check the production possibility of other stable isotopes of experimental interest as well as commercial interest.

Thank You