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CondenSyn Case study

By the University of Liverpool

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The University of Liverpool tested the yields and reaction times for various experiments across the chemistry department. They used this to determine the performance of the CondenSyn, and the potential water savings through switching to CondenSyn from Liebig condensers.

CondenSyn Water Savings

Initial testing by the University of Liverpool found that an experienced chemist uses water though Liebig condensers at a flow rate of 100 mL/minute, whilst an inexperienced chemist uses a flow rate of 700 mL/minute. These figures were used to calculate the total water savings across a cohort of 120 students for various experiments in both scenarios.

Table 1: Potential water savings across five experiments

No.	Experiment	Liebig Use Time (min)	Minimum Water per Student (L)	Maximum Water per Student (L)	Minimum Water Savings (L)	Maximum Water Savings (L)
1.	Distillation of cyclohexanone.	95	9.5	66.5	1,140	7,980
2.	Sn/HCl reduction of 3-nitroacetophenone.	100	10	70	1,200	8,400
3.	Sodium borohydride reduction of 3-nitroacetophenone.	19	1.9	13.3	228	1,596
4.	Alkene Metathesis	90	9	63	1,035	7,245
5.	Ligand Substitutions of a Molybdenum (0) Complex	201	20.1	140.7	2,312	16,181

As shown in Table 1, the total potential water savings across 5 experiments could range from 5,914 L to 41,402 L. As the first three experiments are for 1st year undergraduates undergoing module CHEM130, it is highly likely these will be carried out with much higher flow rates of up to 700 mL/minute. In these experiments alone, close to 17,976 L of water would be used by a cohort of 120 students. The last two experiments are for 3rd year undergraduates undergoing module CHEM3X5, who would be expected to use a lower flow rate. Ligand substitution of a molybdenum (0) complex, however, is a much longer, more complicated, experiment and uses 20.1 L per student at a minimum, resulting in a 2311 L loss across all 120 students.

At a rate of 0.31 p per L based upon rates quoted by UK water agencies in August 2022, this could save up to £128 just across these experiments. Converting to CondenSyn for the three 1st year undergraduate experiments alone could save £55 per year. CondenSyn would pay back the initial costs of purchase after approximately 9 months of operation during working hours in a 1st year lab. Within the labs of more experienced chemists, the payback time would be longer, with the maximum time being several years.

CondenSyn Performance

Table 2: Reaction performance comparison between Liebig and CondenSyn condensers.

No.	Experiment	Condenser	Total Time (min)	Yield (%)	Relative Purity
1.	Distillation of cyclohexanone.	Liebig	95	63	Identical
		CondenSyn	109	65	
2.	Sn/HCl reduction of 3-nitroacetophenone.	Liebig	96	65	Fewer impurities from CondenSyn.
		CondenSyn	100	57	
3.	Sodium borohydride reduction of 3-nitroacetophenone.	Liebig	19	51	Near identical
		CondenSyn	26	42	
4.	Alkene Metathesis	Liebig	90	93	Near identical with same water impurity.
		CondenSyn	90	92	
5.	Ligand Substitutions of a Molybdenum (0) Complex	Liebig	201	58	Near identical
		CondenSyn	191	65	

Table 2 shows that while most experiments were faster with the Liebig condenser, the longest time additionally taken using CondenSyn was only 14 minutes, in experiment 1. Experiment 5 showed that in some cases, CondenSyn starts refluxing sooner than the Liebig condenser, leading to a shorter overall time of the experiment. CondenSyn may also save time setting up, as less time needs to be spent on the water supply and tubing.

The yields between both condensers were quite similar overall. Two of the experiments had negligible differences in yield (experiments 1 and 4), whereas experiments 2 and 3 demonstrated decreases in yield from Liebig to CondenSyn of 8% and 11% respectively. Experiment 5 however showed an increase in yield using CondenSyn of 7%. This may suggest that the optimum condenser may vary from reaction to reaction. Overall, the average yield achieved was only 9% less for CondenSyn, showing that overall, both condensers are relatively equal in terms of achievable yields.

Low-Boiling Solvents

DCM was used as the solvent for experiment 4, which showed very equal yields between results from Liebig condensers and CondenSyn. This shows that solvents with lower boiling points such as DCM with a boiling point of 39.6 °C can be used with the CondenSyn. This does however require carefu control of the reaction temperature to prevent solvent breakthrough, and CondenSyn may be less suited to solvents with lower boiling points than DCM. Reflux experiments were carried out using THF, a solvent with a boiling point of 66 °C to investigate further the performance of CondenSyn with low boiling solvents. The lowest recovery was obtained when refluxing at 66 °C and was attributed to incomplete sealing of the PTFE sleeve at the lower temperatures. However, the solvent recovery improved with increasing temperature, and at 26 °C above the boiling point, the solvent loss was negligible. This shows that for THF, a temperature excess of up to 40 % above the boiling point produces acceptable results.

Total Monetary Savings

Table 3: The total monetary value of the money saved across four chemistry modules, based upon rates quoted by UK water agencies in August 2022.

Module	Water Savings – per student (L)	Money saved - per student (£)	Money saved - cohort (£)/year
CHEM130	12 – 86	4 – 27	796 – 5,573
CHEM3X5	29 – 204	9 – 63	1,038 – 7,262
CHEM245	42 – 291	13 – 90	1,544 – 10,807
CHEM356	72 - 504	22 – 156	1,339 – 9,374
Total	155 – 1,085	48 – 336	4,717 – 33,016

The potential value of water saved across a total of four chemistry modules was estimated using the approximate reaction times, in addition to the two modules where the water saved was determined experimentally. Shown in Table 3, the additional modules CHEM245 and CHEM356 each had large variations in the potential water savings per student. It should be noted however, that whilst CHEM245 had a cohort size of 120 students, the cohort size of CHEM356 was only 60 students. Therefore, for CHEM245, the potential money saved per cohort a year ranges from £1,544 to £10,807 but for CHEM356, the potential money saved ranges from £1,339 to £9,374. As a result, the total potential money saved across all four modules per annum would be £4,717 to £33,016. At the lowest amount, the payback time to cover the cost of 120 CondenSyn would be 4.6 years, however, at the highest water savings, this could be as short as 0.7 years, or 8.4 months.