LOW COST OPTIONS FOR THE USE OF HYDROCARBONS IN THE MANUFACTURE OF POLYURETHANE FOAMS

AN ASSESSMENT FOR APPLICATION IN MLF PROJECTS

- FINAL COMPLEMENTARY REPORT -

SEPTEMBER 2015

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EXECUTIVE SUMMARY

The MLF/UNDP demonstration project on low-cost hydrocarbons (HC) technology was approved at the 58th meeting of the Executive Committee in July 2009, with the main technology report submitted to and approved by the 66th meeting of the Executive Committee in April 2012.

That main report on the potential use of preblended or direct injected hydrocarbons in the manufacture of (rigid) polyurethane foams, identified potential follow-up issues as follows:

- To optimize the three-way injection mixing head;
- To investigate whether system house (SH)-preblended and directly injected approaches lead to lower free rise densities;
- To extend the direct Injection approach to a cost-effective retrofit model;
- To develop a costing concept, and
- To prepare tailored safety concepts for each of the two mentioned approaches.

After a review of previous conclusions, this report summarizes, comments, and draws conclusions on findings from this follow-up work. Based on the initial report, UNDP decided to optimize the mixing head (with the machine supplier - SAIP) and conduct further study on the density effect of system house-blended as well as directly injects CP systems. (with the assistance of Dow Formulated Systems).

IMPROVEMENT OF THE MIXING HEAD

SAIP developed a new mixing head to improve impingement and therefore blending of the injected three components. After some further improvements, this head was installed and trials to address the effectiveness of the system house (SH) -preblended and directly injected systems commenced.

Dow reported that insulation values improved indeed and are now virtually identical to the ones with preblended cyclo-pentane (c-pentane or CP). It can therefore be concluded that

CP DIRECT INJECTION IS AS EFFECTIVE IN THERMAL INSULATION AS PREBLENDED SYSTEMS

They reported on density verification trials as follows:

Test	**Runs : 1,2,3 (avg) CP : Preblend**	**Runs : 4,5,6 (avg) CP : 3rd Stream**	**Notes**
Reactivity	Same reactivity profile: CT : 4-5 , GT : 55-58 . TFT : 88-90		
Free rise density 0.5 hr	24.40	24.24	Normal difference & deviation
Free rise density 24 hr	25.07	25.20	Normal difference & deviation
Crocodile	25.07	25.20	Normal difference & deviation
Flow Index 0,5 & 24 hr ,	1.315 / 1.275	1.324 / 1.295	
At 10 % OP			
Compression Set	145	140	
10^0C mean temp	20.00	20.46	0.46 - 0.5 advantage for preblend
23^0C mean temp	21.45	22.03	0.46 - 0.5 advantage for preblend
At 15 % OP			
Compression Set	155	156	
10^0C mean temp	20.45	20.49	In range
23^0C mean temp	21.38	21.88	0.46 - 0.5 advantage for preblend

From Dow's report it is concluded that.

A DIRECT STREAM APPROACH PROVIDES NO DENSITY ADVANTAGE OVER PREBLENDED SYSTEMS

UNDP designed a simplified safety system for both approaches—SH-preblending and direct injection. While the basic requirements remain the same as for enduser blending, the simplification requires less exhaust, less sensors and less piping as a result of eliminating the need of a preblender. As preblending is an operation that most foam manufacturers are not used to, there are benefits from simplified operations as well. Overall cost savings are estimated to be US$ 50,000 - 100,000 per project.

The overall conclusions of this pilot project are that:

- Preblended cyclopentane systems are sufficiently stable and can be commercially used;
- Preblended normal-pentane (n-pentane) systems are unstable and not recommended for commercial use. However, in direct injected systems, normal-pentane as well as cyclo-pentane (c-pentane) can be used;
- Direct injection with c-pentane (CP) can achieve the same effectiveness as preblended systems in view of density and thermal insulation when using optimized equipment;
- Any performance differences between end-user blended and SH blended systems is most likely related to blending and handling operations with the SHs being more precise;
- Indicative differences in density between the different ways to apply HCs could not be substantiated;
- Cost savings from SH-blended and direct injection compared to enduser-blended systems are in the range of 50,000 - 100,000 US$, and
- Simplified safety requirements apply

There are now three equipment suppliers that UNDP is aware of that offer direct injection of blowing agents:

- Cannon/Italy used in UNDP pilot projects for MF and ML in Brazil;
- OMS/Italy focusing on retrofit;
- SAIP used in the UNDP pilot project for HCs in Egypt.

As to preblended systems, apart from Bayer, who has supplied commercially preblended systems in Eastern Europe, Pumex/Mexico has developed CP preblended systems as part of an MLF/UNDP project. Pumex is offering these systems to all its customers that are willing to comply with safety requirements developed by the system house. It has produced videos showing safe operational practices and fire behavior of resulting products.

Recently Pumex has conducted extensive trials in the sprayfoam sector with good results. It expects to have replaced 70% of its HCFC-141b consumption by the end of the year, mostly by cyclo-pentane and is participating in a UNDP demonstration project sponsored by the US State Department in which it will address CP/HFO blends.

1. INTRODUCTION

In the main technology assessment report on potential use of preblended or direct injected hydrocarbons in the manufacture of (rigid) polyurethane foams, submitted by UNDP in March 2012 for the consideration at the 66th meeting of the Executive Committee, potential follow-up issues were identified as requiring further investigation:

- To optimize the three-way injection mixing head;
- To investigate whether the tentative fact that preblended and directly injected approaches in the use of pentane and cyclopentane lead to lower free rise densities can be substantiated;
- To extend the Direct Injection approach to a cost-effective retrofit model;
- To develop a costing concept based on this report as well as the follow-up outcome; and
- To prepare a tailored safety concept for each of the two mentioned approaches.

SAIP, UNDP's partner in the development of a direct injection dispenser and Dow, UNDP's partner in the development of preblended hydrocarbon (HC) systems, were contacted and two tasks were developed:

- With SAIP, the optimization of the mixing head of the dispenser provided under this project;
- With Dow, to conduct a follow-up study on the possible (beneficial) density effect of preblended or directly injected cyclo-pentane.

After receiving the outcome of these tasks, UNDP would then decide, how to address the other mentioned issues, which are:

- Preparation of tailored safety concepts for direct HC injection and preblended HC systems;
- Possible extension of the Direct Injection approach to a cost-effective retrofit model; and
- A costing concept based on this original as well as the follow-up findings.

This report summarizes and comments on the findings from Dow, SAIP and the follow-up work by UNDP and can be considered a final complementary report on the issue. It has been delayed because of:

(i) management changes at Dow Italy who had directed the original study—making it necessary to move the entire task to Dow-Egypt;
(ii) political unrest in Egypt which caused delay in conducting the necessary trials; and
(iii) initially inconclusive results on density benefits, necessitating a change in the trial set-up.

There has been considerable time passed between the initial report—March, 2012 which was considered final at that time—and this "final" complementary report—September 2015 that addresses issues highlighted in the initial report that the ExCom deemed worth pursuing. It would be of interest to review in how far preblending and/or direct injection have progressed in the market and what the effect(s) have been on technology and chemical systems. UNDP has added a brief review to that matter to this report.

This report starts with a review of previous conclusions as mentioned in the initial and the first follow-up complementary report. It proceeds then with a description of equipment and chemical development work that has been performed based on suggestions from the initial report. The report continues to address issues of safety and costing and then draws conclusions from the follow-up work as well as conclusions from the consolidated work and closes with a review of current market activities on preblended/direct injection of hydrocarbons.

UNDP acknowledges the work by Dow as well as SAIP in chemical and equipment development. It is also grateful to Pumex/Mexico for sharing information on their work in bringing preblended cyclo-pentane into the market.

2. SUMMARY OF THE INITIAL REPORT

The initial main technology report offered conclusions that can be summarized as follows:

PREBLENDED HYDROCARBONS (HCs)

- Pre-blended cyclo-pentane (CP) systems are sufficiently stable and can be commercially used;
- No preblender and related (tanks, piping) equipment needed, leading to savings of around US$ 100,000;
- There were indicative costs savings expected from lower densities. However, more research was needed to confirm this. If confirmed, the overall difference in operating costs was estimated between 6 and 8%;
- Against this, the possibility of higher transportation costs needed to be considered;
- K-values are 5-8% higher than for HCFC-141b foams but equal to conventional c-pentane (CP) foams.

USE OF NORMAL PENTANE (NP)

- Preblended NP systems are stable for less than a month and therefore not recommended for use;
- In case of direct injection, normal-pentane as well as cyclo-pentane can be used;
- The k-values achieved with direct-injected n-pentane are inferior leading to the conclusion that this substance should not be used in critical thermal insulation applications.

DIRECT INJECTION

- Equipment developed for direct HC injection shows good reproducibility and consistency as well as homogenous mixtures, despite higher polyol viscosities;
- The three way mixer head showed insufficient impingement and needed redesign;
- Free blown densities from direct injection are even lower than for preblended cyclo-pentane;
- No preblender along with auxiliary equipment (tanks, piping, etc) is needed but the need for a third dosing line might absorb most, if not all of these savings;
- Based on lower comparable densities, incremental operational costs savings of up to 10% can be expected when using direct injection. This statement still needed confirmative through further trials.

PROPOSED FURTHER WORK

Dow, who performed the experimental work of this project reported that “Third stream addition of pentane, in the specific of System B has a positive effect in lowering the free rise density (better blowing efficiency)….In principle this seem to indicate that third stream could allow to go for slightly lower applied densities.”

Dow also recommended as future work optimization of pentane impingement pressure and reactivity to close the delta in gel time and thermal conductivity that were observed vs pre-blended process.

Based on Dow’s findings and recommendations, UNDP decided to optimize the mixing head (with the machine supplier SAIP) and conduct further study on the density effect of system house-blended as well as directly injects CP systems.

3. FOLLOW-UP WORK

A first follow-up complementary report dated September 2014 reported inconclusive results based on problems with a new three-way mixing head. This kept Dow-Egypt from making sufficient trials and final conclusions.

It appeared that the favorable density effect compared to conventionally prepared c-pentane (CP) blends still exists but because of the mentioned technical problems with the mixing head, this finding was not conclusive. Further mixing head revisions were implemented followed by more trials. As reported, the political situation in Egypt caused some delays in the program as well.

IMPROVEMENT OF THE MIXING HEAD

SAIP provided a new mixing head to improve impingement and blending of the injected three components. After some further improvements, this head was installed with trials implemented in 2015.

Subsequently, Dow-Egypt reported that insulation values improved and are now virtually identical to the ones with preblended and conventionally blended (in situ with a locally installed preblender) cyclopentane. It can therefore be concluded that

CP DIRECT INJECTION IS AS EFFECTIVE IN THERMAL INSULATION AS PREBLENDED SYSTEMS

DENSITY VERIFICATION TRIALS

Six machine evaluations were conducted using a refrigeration system (Voracor CR 1070):

- Three with preblended CP (in the polyol);
- Three with CP as third stream directly in the mixing head

The outcome of these trials can be summarized as follows:

Test	**Runs : 1,2,3 (avg) CP : Preblend**	**Runs : 4,5,6 (avg) CP : 3rd Stream**	**Notes**
Reactivity	Same reactivity profile: CT : 4-5 , GT : 55-58 . TFT : 88-90		
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No further comparison between densities from system house (SH) and recipient (end-user) Preblending has been conducted. As the operation is basically the same—just executed at different locations—it is believed that any difference is related to better procedures at system houses, resulting in less loss of blowing agent.

Current tests on MF, ML and HC blends with HFOs in Mexico (a USA sponsored project) show that ABA losses can be considerable and that proper procedures against evaporation from blends are important.

Attachment-1 contains Dow's detailed test reports and describes the test methods used. From the report it is concluded that.

A DIRECT STREAM APPROACH PROVIDES NO DENSITY ADVANTAGE OVER PREBLENDED SYSTEMS

SAFETY

By not requiring a preblender with auxiliaries, both systems—(SH) Preblending and Direct Injection—allow for a simplified safety system. While the basic requirements remain the same, the simplification requires:

- Less exhaust
- Less sensors
- Less piping

Also, an operation that most foam manufacturers are not used to—system blending—is not anymore required. **Attachment-2** shows the simplified safety requirements for a refrigerator system.

COSTS

The removal of a preblender with auxiliaries from the cost of a conversion from HCFC-141b to cyclo-pentane should save around US$ 80,000-100,000 per project. In case of direct injection, this cost reduction is partly reduced by the cost increase of the dispenser (estimated on US$ 30,000). Currently, Cannon, OMS and SAIP offer such dispensers. However, direct injection allows for more economic retrofit of existing dispensers as a study by Impianti OMS states (**Attachment-3**).

4. CONCLUSIONS

CONCLUSIONS FROM THE FOLLOW-UP REPORT

Conclusions from the additional work carried out on behalf of UNDP and summarized before, is that

- Direct injection with CP can achieve the same effectiveness as preblended systems in view of density and thermal insulation **when using optimized equipment;**
- Any performance differences between end-user blended and SH blended systems is **most likely related to blending** and handling with the SHs being more precise;
- Indicative differences in density between the different ways to apply HCs could not be substantiated;
- Cost savings from SH-blended and direct injection compared to end-user blended systems are in the range of US$ 50,000 - 100,000, and
- Simplified safety requirements apply.

This, combined with the conclusions from the initial report lead to the following.

CONCLUSIONS FROM ALL REPORTS

- Pre-blended cyclopentane systems are sufficiently stable and can be commercially used;
- Cost savings from SH-preblended and direct injection compared to end-user blended systems are in the range of US$ 50,000 - 100,000:

- Preblended normal-pentane systems are unstable and not recommended for commercial use. At the same time, for direct injected systems, normal-pentane as well as cyclo-pentane (c-pentane) can be used;
- Direct injection with c-pentane can achieve the same effectiveness as preblended systems in view of density and thermal insulation when using optimized equipment;
- Any performance differences between end-user blended and SH blended systems is most likely related to blending and handling operations with the SHs being more precise;
- Indicative differences in density between the different ways to apply HCs could not be substantiated;
- Cost savings from SH-blended and direct injection compared to end-user blended systems are in the range of US$ 50,000 - 100,000, and
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EXPERIENCE FROM THE MARKET

There are now three equipment suppliers that UNDP is aware of that offer direct injection of blowing agents:

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ACKNOWLEDGEMENTS

UNDP thanks Dow Formulated Systems, Middle East and Africa—in particular Mr. Adel Momen and Mr. Mohamed El Fikky—for their help in carrying out the necessary trials to conduct the follow-up study.

5. ATTACHMENTS

Attachment-1 Detailed Report from Dow Formulated Systems
Attachment-2 Simplified Safety requirement for the use of Hydrocarbons utilizing SH-preblended or direct-injected systems
Attachment-3 E. Greco, G. Podrecca, “Direct Injection of Blowing Agent into the Mixing Head as a Third Stream” PU Magazine, 05/20150