Institution: University of Salford

Unit of Assessment: 12

Title of case study: Cutting hydrocarbon emissions through novel aerosol valve designs

Period when the underpinning research was undertaken: February 2007 – May 2016

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Ghasem Nasr	Associate Dean Research & Innovation; Head of Sprays & Petroleum Research Groups	February 2002 – Present
Dr Amir Nourian	Lecturer in Mechanical and Petroleum Engineering	December 2011 – Present

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? Y

1. Summary of the impact

Almost all aerosol products utilise hydrocarbon propellants, such as blends of Liquefied Petroleum Gas (e.g. butane) as the primary propellant. Since they contain a high level of Volatile Organic Compounds (VOC) and greenhouse gas, these propellants contribute significantly to air pollution and directly impact the environment and human health (19 billion aerosol spray cans produced and used globally each year). Their use is increasingly being discouraged through international and national regulations (Kyoto Protocol, 2005; UK Government's Clean Air Strategy, 2019). Since the inception of the first conventional aerosol valve 50 years ago, there has been no change to valve design, prompting Salford researchers to develop new environmentally friendly aerosol valves that do not rely on hydrocarbon propellants. These trademarked Eco-Valves have now been commercialised through spin-out company Salvalco at their production facilities in China and are available on the market to both SMEs and FTSE companies, including **[text removed for publication]**. Salvalco saw turnover increase to **[text removed for publication]** through direct sales in 2020, with revenues forecast to rise to **[text removed for publication]** by 2023. Without Salford's innovative Eco-Valve, an additional 1,437kt of harmful VOC would have been emitted into the Earth's atmosphere by 2020.

2. Underpinning research

Since 2007 the aim of ongoing research by the University of Salford's Spray Research Group (SRG) has been to design and develop low VOC valves for domestic aerosol products using inert gas propellants such as compressed gas or nitrogen. This was achieved by designing a laboratory prototype in creating the 'bubbly flow' structure inside the conduit of the flow passage of the valve in the upstream of the nozzle exit arrangement (actuator-insert). The bubbly flow was created by carefully designing and developing the correct geometry of the relevant orifices and the mixing chamber that were located inside the valving arrangement. Such precision engineering design led to the flow becoming highly energised and turbulent which subsequently led to the formation of the required laden of bubbly flow.

The common thread of the underlying research was to: (i) produce spray that looks and feels good, (ii) provide constant pressure drop of the nitrogen propellant (bar) upon usage, (iii) give constant spray discharge rate (g/s) and (iv) constant particle size (micron) throughout the life of the can. The performance of the spray should also have minimum dropout (rainy effect) and provide acceptable reach (m) with minimum wetness (subjective). These low VOC valves use

the standard components with no manufacturing penalties and most importantly use no harmful gas such as butane or other Liquefied Petroleum Gas (LPG) propellants.

The key research findings were:

- **2014 Actuator-insert design:** The concept of the two-fluid atomisation, also known as 'bubbly flow', was utilised in determining the efficacy of linking spraying quality to atomizer designs in conditions where inert compressed gas acted as the propellant in the container of the spraying (aerosol) device, leading to novel actuator-insert (nozzle exit arrangement) designs. The interaction of the bubbly flow with the actuator-insert causes a flow attachment and reattachment phenomenon, generating a highly energised and turbulent state **[3.1, 3.2]**.
- **2016 Eco-Valve design (continuous spray):** The bubbly flow was also generated by injecting a small proportion of propellant directly into the passing flow of product within the low VOC aerosol valve assembly. The propellant is directly tapped off from the head space within the aerosol can. The technique therefore acts to reduce the subsequent droplet size of the product when dispensed from the valve through the actuator-insert, generating superior spray characteristics. In addition, by controlling the ratio of liquid to gas injected within the valving arrangement (via selecting the correct geometry of the orifice sizes in the correct ratio), the maintenance of consistent spray performance is enabled with regard to constancy in the inert gas propellant pressure, discharge rate, dropout, wetness and the reach, throughout the life of the can **[3.3]**.
- **2015-2019 Metering Eco-Valve (meter dosage spray):** There was also demand through the research for a special new 'metering - low VOC aerosol valves' which can use inert gases rather than liquefied gas propellants. Such a valve had never been successfully developed in the past. 'Continuous spray' with bubby flow research has therefore enabled the team to develop a novel compressed (inert) gas propellant metering valve suitable for both consumer air fresheners and health applications (i.e. nasal sprays) **[3.4, 3.5]**.
- **2014-2018 Low-loss valve (viscous continuous spray):** A different approach was required in order to spray 'difficult liquids' that tended to be viscous (up to 100 centipoise) and/or emulsions or suspensions. This was a fourth strand of the research which led to the development of new 'low-loss' valve designs that permit the spraying of such liquids (i.e. food products, oil, dry shampoo or portable fire extinguishers) and successfully use compressed gas propellants **[3.6]**.

Publications **3.2**, **3.3** and **3.5** are examples of the patents that were initially transferred to the AWI Group by the University of Salford through a technology transfer mechanism. A spin-out company was set up in November 2013 under the trademark name 'Salvalco Ltd.' (Salford Valve Company Ltd.). The research team continues to work with the company and has filed a further six granted patents to date prior to and during the manufacturing and assembly operations.

3. References to the research

Research ongoing since 2007 is represented through a sample of outputs illustrated below. This includes papers which have been published in three leading peer-reviewed international journals **[3.1, 3.4, 3.6]** and examples of patents granted **[3.2, 3.3, 3.5]**.

3.1. Burby, ML, **Nasr, GG**, Yule, A.J. Hawthorne, G and Asmuin N. Novel aerosol insert design utilizing inert compressed gas, *Atomization and Sprays*, 24(12), 2014, pp. 1035-1063. https://doi.org/10.1615/AtomizSpr.2014007903 **(REF2)**

3.2. Nasr, GG, Yule AJ and Burby ML, Spray Discharge Assembly, Patent, US 9296549 B2, 29.03.2016

3.3. Nasr GG, Nourian A, Goldberg T and Hawthorn G, Valve Assembly, Patent, GB2526821B, 27.04.2016

3.4. Nourian A., G. G. Nasr, Yule A.J., G. Hawthorne and T. Goldberg, Novel metered aerosol valve, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* Vol 230, Issue 10, 2016, pp. 1557-1568.

https://doi.org/10.1177/0954406215572839
3.5. Nasr GG, Yule AJ, Burby ML, Liquid Dispensing Apparatus, Patent, EP2485966B1, 11.05.2016
3.6. Nourian, A., Nasr, G.G., Pillai, D. and Waters, M., Compressed gas domestic aerosol valve design using high viscous product, *The International Journal of Multiphysics*, 8(4), 2014, pp. 437-460. https://doi.org/10.1260/1750-9548.8.4.437 **(REF2)**

A total of GBP850,000,000 funding is associated with the underpinning research, namely grants awarded from Innovate UK (TSB-Smart 720417 (May 2014) and 274201 (Nov 2014)).

4. Details of the impact

The current standard propellant is a hydrocarbon gas (LPG) whose boiling point is just below room temperature. Upon pressurisation within the can LPG turns into liquid form. As the product is sprayed, the propellant flash-vaporises to leave a fine atomised spray. Originally chlorofluorocarbons (CFCs) were used as they provided the ideal characteristics. These were banned following the Montreal Protocol (1989). Highly flammable propane, n-butane and iso-butane are hydrocarbons that are now widely used, but because these gases are hazardous, numerous regulations have been enforced, including the Gothenburg Protocol (1999) and the Kyoto Protocol (2005). This was followed by the Paris Agreement in 2015 on the safe transport and storage of aerosols within the supply chain, and, once used, on their safe disposal. The low VOC aerosol valves developed by Salford's SRG are an alternative technology utilising compressed gas as a propellant, providing excellent spray performance while being compatible with conventional aerosols using LPG propellant. The aim is to create a cleaner environment with significant benefit to consumers' health and wellbeing.

The success in developing these technologies and their measurable impact is best illustrated with reference to: (i) the spin-out company (ii) investment in new manufacturing facilities and (iii) the industrial outlets that have made direct use of the products (customers):

4.1. Development of the spin-out company

The spin-out company, AWI Group, was established in November 2013 through a University technology transfer under the trademark name 'Salvalco Ltd.'. The company, which operates as a separate entity with its head office in York, currently employs 12 staff in the UK and has had **external investment totalling approximately [text removed for publication] since 2014**. Salford's SRG has continued supporting the company through Professor Nasr (Non-Executive Director of Innovation and Technology).

The filing of patents and securing of 'Smart' grants for the next generation and development of VOC-free aerosol valves and actuators have enabled the company to take the initial laboratory prototype to **full industrial commercialisation [5.1]**. Impact was further increased by the **novel methods employed in moulding the components of the valves**. This entailed a new design of 'hot runners' injection and assembly machines together with the precision engineering of the complex geometries of the actuator-inserts (nozzle exit). Salvalco had to establish **new manufacturing solutions** in creating the conditions that were needed for production of a mould tooling stacks arrangement for a 3-parts Eco-Valve, as opposed to the conventional 2-parts valve. This enabled a number of running moulding cavities on each production cycle to be aligned to the number of required pieces for mass production **[5.1]**. The final products (valves and actuators) were therefore able to meet the underlying criteria for acceptable spray performance when using clean air propellant, such as nitrogen, compared to harmful LPG **[5.1]**. Salford's SRG also supported the company in **devising Salvalco's Quality Control Document for validating corresponding spray performance**, which ensured that an effective quality management system was put into place to comply with the requirements of ISO 9000 or comparable standards **[5.2]**.
The company was recognised for its achievements, winning the *Times Higher Education* (THE) award for '*Outstanding Contribution to Innovation and Technology'* in November 2014, with the

panel of judges confirming that *'Its green credentials, safety applications and industrial promise make it a worthy winner'* **[5.3]**.

4.2. Investment in new manufacturing facilities

(i) The partnership between Salvalco and **[text removed for publication]** based in China and Taiwan) played a key role in **establishing new facilities**, which included the moulding process and semi-autonomous assembly lines of the valves in 2014 **[5.1]**. This led to the launch of products in 2015, supported by the research team in the UK **[5.4]**. **[Text removed for publication]** employs 14 staff and made **an investment of [text removed for publication] in mould tooling and manufacturing assembly lines**. **[Text removed for publication]** was also given a **licence to sell the products to the Chinese and Korean markets**, with royalties to Salvalco **[5.1, 5.5]**.

(ii) In April 2018, **[text removed for publication]** also **invested [text removed for publication] in the technology**, with **additional investment of [text removed for publication] in August 2019 [5.1, 5.6]**. These contributions were key to enabling Salvalco to re-strategise its direction and resources in pursuit of its commercialisation goals on a global scale, by appointing several sales agents, business managers and licensing experts. The investment also enabled the company to **further innovate and meet the required demand of the leading brands for 'spray-through caps' for aerosol containers [5.7]** that are used in body sprays and antiperspirants in conjunction with the low VOC valves.

Salvalco had a **turnover of [text removed for publication] through direct sales in 2020** and is expected to generate **[text removed for publication]** by 2021 through a combination of direct sales and licensing, through know-how or manufacturing. The Managing Director of Salvalco confirms that by 2023, the Eco-Valve will have a **significant market share**, with over **[text removed for publication]** valves sold and projected revenue of **[text removed for publication] [5.1]**.

4.3. Key customers (2016 onwards)

The normal protocol for evaluating aerosol products in all SMEs and leading-brand companies takes a period of 3 years. This is to confirm and validate the shelf life of the filled cans (which should be more than 2 years) and to conduct full consumer testing prior to market. The low VOC aerosol valves are subject to the same evaluation and protocol: the UK Government's Clean Air Strategy 2019 requires these traditional aerosol companies to move faster towards VOC-free aerosol usage and at the same time adapt more efficient protocol evaluation. The aerosol industry is required to '*reduce emissions of VOCs, against the 2005 baseline, by 32% by 2020 and increasing to 39% by 2030'* for all their domestic and industrial products. According to the British Aerosol Manufacturers' Association, should industry choose not to act, there is a real risk of punitive regulation. In response, Salvalco has begun to rapidly establish itself in the market and its low VOC aerosol Eco-Valves are the only option for industry to achieve the target for emissions set by the UK Government.

There are currently **15 major customers around the world** using the low VOC aerosol Eco-Valves, with **total orders ranging between [text removed for publication] valves over the next 12 months**. Key accounts include:

[Text removed for publication] USA: following the development phase from August 2019 to August 2020 the global manufacturer approved and launched an aerosol product using the Eco-Valve in October 2020. This was in compliance with new California Air Resources Board (CARB) regulations for the use of safe propellant (compressed gas). The product is used for spraying adhesive on various products such as clothing and carpets and the company placed an order starting at **[text removed for publication] [5.1, 5.8]**.

[Text removed for publication] Germany: the multinational company manufactures and retails personal care products **[text removed for publication]** as well as pressure-sensitive adhesives

and has worked with Salvalco, its Chinese supplier and Salford's SRG since 2018 to test the Eco-Valve on various products **[5.9]**. In March 2020, the company entered into partnership with Salvalco **[5.1]** and requested a **capacity reservation for 10,000,000 pieces per annum**. The full launch of the deodorant product takes place in 2021, resulting in the entire filling plant in the EU being switched over to VOC-free valves. This equates to **sales revenue of [text removed for publication] [5.9]**.

[Text removed for publication] **Italy:** the company specialises in cosmetic and medical aerosol products and, following 12 months of stability and compatibility testing during 2019 and 2020, obtained final approval for the Eco-Valve in February 2020. The first **annual order for 500,000 pieces** was placed with Salvalco in July 2020, with a further order in October 2020 **[5.1, 5.10]**. The company has capacity for 80,000,000 filled cans per annum and, following the standard 3-year aerosol protocol evaluation process, launches its first eco-friendly deodorant and sun care product using the Eco-Valve in early 2021 **[5.10]**. The company has **targeted 9,000,000 sales [text removed for publication]** for both products and will convert all of its aerosol products before 2023 in line with its sustainability strategy of zero emissions using 'clear air' propellant **[5.10]**.

Other companies committed to converting their products using VOC-free Eco-Valves include **[text removed for publication]** **Mauritius**, a manufacturer of personal care and home care products which launched its **[text removed for publication]** products using the Eco-Valve in March 2020, initially ordering **500,000 pieces per annum [text removed for publication] [5.1, 5.11]** and **[text removed for publication]** **Germany,** a major drug store chain that launched its deo-spray for men in November 2020 with an **annual order of 300,000 pieces [text removed for publication] [5.12]**.

5. Sources to corroborate the impact

5.1. Testimonial: Salvalco Ltd. (November 2020), on the full industrial commercialisation process (4.1), partnerships and investments as well as current/projected revenue and market share (4.2) and detail on key customers (4.3)
5.2. Salvalco Quality Control Document (2015, revised 2019), confirming establishment of a quality management system in compliance with ISO 9001 and other comparable standards (4.1)
5.3. THE (*Times Higher Education*) Award for '*Outstanding Contribution to Innovation and Technology'* (November 2014) (4.1)
5.4. Keynote Speech: Ningbo Hygiene and Insecticide Fair (November 2015), confirming launch of products in 2015 (4.2)
5.5. Agreement: **[text removed for publication]** and Salvalco Ltd., confirming licence for manufacturing and assembly lines of Low VOC Valves (4.2)
5.6. Flyer: **[text removed for publication]** (April 2018), confirming investment in 2018 (4.2)
5.7. Flyer: Salvalco spray-through caps (2019), confirming further innovation from investment (4.2)
5.8. Product launch label: **[text removed for publication]** USA (October 2020), confirming approval and launch of an aerosol product using the Eco-Valve (4.3)
5.9. Testimonial: **[text removed for publication]** Germany (November 2020), on partnership with Salvalco and request for a capacity reservation (4.3)
5.10. Testimonial: **[text removed for publication]** Italy (December 2020), on annual order placed in 2020 (4.3)
5.11. Product launch label: **[text removed for publication]** Mauritius (March 2020), stating its eco-friendly aerosol credentials on product label in 2020 (4.3)
5.12. Product launch label: **[text removed for publication]** Germany (November 2020), stating its eco-friendly aerosol credentials on product label in 2020 (4.3)