Developing Transfer: Improving Household Water Supply in Rural Cambodia

Christopher Browne
Australian National University, Canberra, ACT
Engineers Without Borders, ACT Chapter

ABSTRACT

Clean water is requisite for life. In locations where no centralised water distribution system exists, household-level ceramic filtration is relied upon to access water free of pathogens. This technology can be low-cost and simple to manufacture locally, making it an ideal candidate technology to deliver clean water in developing countries. Despite this, the innovation in the field experiences disuse over a short period of time. My research asserts that this disuse is a breakdown of technology transfer, and provides a framework for improving usage rates and in turn the health of its users.

Ceramic water filter (CWF) technology was introduced to Cambodia in 2001 under the World Bank's Water and Sanitation program. In 2007, Engineers Without Borders Australia (EWBA) began to provide technical assistance to the Resource Development International - Cambodia (RDIC) ceramic filter factory to enable upscaling of CWF production within Cambodia. This research extends the relationship between EWB and RDIC by identifying potential areas of concern around the supply of this household-level technology as RDIC seeks to increase its production.

By investigating the trend of disuse, my research proposes that this is not a simple linear problem. Manufacturers and distributors need to address issues at all three levels of technology transfer: technology development to improve usability and maintenance of the CWF; technology acceptance exercises to build confidence in the capability of the CWF, and; technology application processes to ensure that the CWF is in continuous use. By identifying suitable leverage points, this research provides a framework for reducing discontinuance by positioning the CWF as a fundamental service rather than a luxury product.

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ABSTRACT

Clean water is requisite for life. In locations where no centralised water system exists, household-level ceramic filtration is utilised to access water free of pathogens. This technology is both low-cost and simple to manufacture locally, making it an ideal candidate technology to deliver clean water in developing countries. Despite this, the innovation in the field experiences disuse over a short time interval. This paper asserts this disuse is a breakdown of technology transfer, and provides a framework for improving usage rates and in turn the health of its users.

OUTLINE

The *Introduction* provides the aims, needs and background of the research. The *Statement of Hypotheses* indicates the three stages of the research. The *Contextual Background* includes an overview of the foundation theories used in the context of the project, which leads into the three-part *Evaluation*. The *Discussion* indicates recommendations to improve the technology transfer of the innovation based on theory, and the *Conclusion* provides a reflection on the work undertaken and potential areas of further research. Finally, the *Acknowledgements* pay tribute to those whom helped directly in this project.

INTRODUCTION

Research Aim and Need

In 2007, Engineers Without Borders Australia (EWBA) began to provide technical assistance (RDIC 2007) to the Resource Development International - Cambodia (RDIC) ceramic filter factory to enable upscaling of ceramic water filter (CWF) production within Cambodia. The aim of this research is to identify areas of concern around the supply of this household-level technology as RDIC looks to increase its production.

Successful transfer of knowledge and technology is critical to the success of both RDIC's business model and any development activity. A field note undertaken by the World Bank-administered Water and Sanitation Program (WSP 2007) observes that filters experience disuse over time, as shown in Figure 1. This disuse means that users are not gaining the benefits from using the technology, and are also not encouraging further users to adopt.

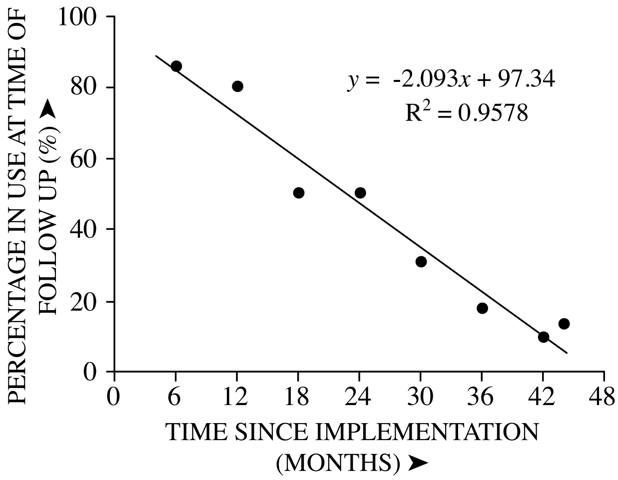


Figure 1: Filter disuse over time, WSP (2007)

By investigating the trend of disuse, this paper proposes that this failure can be seen as a breakdown in the transfer process. It considers the model in a diffusion of innovations framework, and builds upon the dynamical approach proposed by Ngai and Fenner (2008). This paper contributes to this work by using the theory to identify suitable leverage points, and provide a novel framework for reducing discontinuance by positioning the CWF in the market as a service rather than a product.

As 2011 is the Engineer's Australia Year of Humanitarian Engineering, it is apt to reflect that the knowledge and technology that is often transferred to developing countries for profit or financial gain can also be used as a vehicle for social change and improvement of health conditions in those countries.

Project Background

In situations where there is no centralised water supply, considerable time is spent collecting water from various sources, such as wells, streams, lakes and bores (Grey 2006). This is extremely time and labour intensive, and has an impact on health and wellbeing. The water collected is often not fit for drinking due to high turbidity and bacterial levels. Numerous methods for treating and improving water for drinking exist; however, this study only considers ceramic filtration at the household level.

The CWF has been used as a targeted approach to improving household drinking water quality in Cambodia since 2001 (WSP 2007). 80% of Cambodians live in rural areas, and only 40% have access to an improved water source (UN 2007). In 2003, RDIC established a CWF manufacturing facility near the capital, Phnom Penh, and produces CWFs using local material and labour.

STATEMENT OF HYPOTHESES

This paper investigates the following hypotheses:

1. *CWF disuse is not linear*
   That the CWF innovation undergoes disuse similar to that of the discontinuance in transfer theory after the adoption decision, rather than the linear relationship suggested in WSP (2007).
2. *Maintenance can reduce disuse*
   That a maintenance mechanism improving knowledge transfer could be used to reduce discontinuance.
3. *A service model can reduce disuse*
   That transfer could be improved by considering the innovation as a fundamental and continuous service, rather than a discrete product.

By showing that Hypotheses 1 holds in this case study, it can be explored in the context of the identified theories in the following section. This then will allow the exploration of hypotheses 2 and 3.

CONTEXTUAL BACKGROUND

This section outlines the theory used for the research. It should be noted that much of this section is an application of theory to situations in which it has not previously been explicitly applied, such as Transfer, Diffusion and Discontinuance in a development context. Therefore, this is to be considered as a contextual background that extends on traditional background materials.

Ceramic Filtration

The application of ceramics to water filtration has been documented since the early 1980s, originally by Dr Mazariegos (Lantagne 2001). As a porous medium, clay strains out harmful microorganisms from water (Brown 2007). This is achieved by mixing organic matter of suitable grain size, such as used coffee grounds, with the ceramic when it is in the plastic state. The organic matter burns out during firing, and allows flow rates of 1-3L/hr (WSP 2007). RDIC manufacture this in a filter kit that costs between US$8-$10 (Hagan *et al.* 2009), and is shown in Figure 2.

Figure 2a: Photo of ceramic filter unit (Photo: Judy Hagan 2009); 2b: schematic of filter in use (WSP 2007)

The filtration occurs as a function of the pore size in the ceramic. The larger the pore size, the larger the micro-organism that can pass through it. E. coli is the primary bacterium for removal by filtration, as it is directly linked to the occurrence of diarrhoeal disease when ingested (Foppen et al. 2007; Brown 2007). Ceramic filtration can filter above 99% of E. coli (Flynn 2005; WSP 2007). Ceramic filters cannot filter out viruses or treat groundwater that is contaminated with arsenic (WSP 2007). As such, a safe water supply is required for ceramic filtration.

The ultimate objective of the CWF is to improve the quality of water. This benefits the user by reducing the likelihood of the user becoming sick through drinking contaminated water, and thus improving their quality of life, and employment and education opportunities. When compared to non-filter methods, the CWF has been shown to reduce diarrhoeal instances by half (Brown 2007), diarrhoeal disease being the number one cause of death and disease in children (WSP 2007).

Attitudes Towards Water, Sanitation and Health

Water, sanitation and health are three key target areas that will help towards achieving the UN millennium development goals. Approximately two-thirds of Cambodians are without access to improved water sources (WSP 2007), even though the majority live near major water sources. Less than one-fifth have access to improved sanitation (UN 2008). The sources of water used in filtration for drinking is summerised in Figure 3.

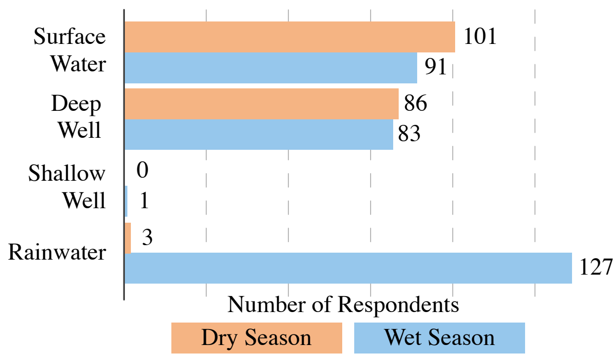


Figure 3: Water sources used for filtration (derived from data in Brown 2007)

This lack of access to improved water and sanitation in Cambodia has a serious health affect on the population. In a survey undertaken in Brown (2007) on water-use behaviour, the majority of respondents had not received health education. Approximately half of respondents report always washing hands with soap at critical times, and approximately half of respondents report using hands when drinking from the filter. This highlights that the technology is one part of a multifaceted problem. The CWF is one of many steps for Cambodia on the development path.

Technology and Knowledge Transfer

As with development, transfer of knowledge and technology is complex, and requires a truly multidisciplinary approach (Seely 2003). Transfer of small-scale, grassroots technology is not a widely explored topic: much of the transfer-to-developing-countries literature focuses on setting up offshore manufacturing for competitive advantage, such as cheaper labour.

There are three levels of transfer required for what is labelled 'successful' transfer: technology development; technology acceptance, and finally; technology application. Rogers (2003) describes the end point of transfer as a 'reinvention', where the receiver adapts and customises the innovation to their given situation.

The CWF in Cambodia has reached a level on the threshold between technology acceptance and technology application, depending on the region and individual user. It is at this level that continued evaluation of the technology is required to ensure that it remains active practice, and reach the aforementioned 'reinvention'.

In a Western situation, the result of a failure at the technology-application level would result in the customer adopting a competitor's product. In a situation where there is little alternative, and the likely scenario is for the former user to consume dirty water, it places the former user at unnecessary risk. It is this risk that amplifies the need for ongoing evaluation of the transfer process.

Diffusion and Discontinuance

When an innovation is exposed to a market, the diffusion process can be mapped in an S-shaped curve. Different products will map to the classic S-shaped curve on different scales. Different categories of receivers in the transfer process play a distinct role in the diffusion of an innovation.

Rogers' (2003) widely accepted definition is the social breakdown of the adopters of innovations, shown in Figure 4. Innovators and early adopters play a crucial role in the diffusion process, as often they are considered as trendsetters.

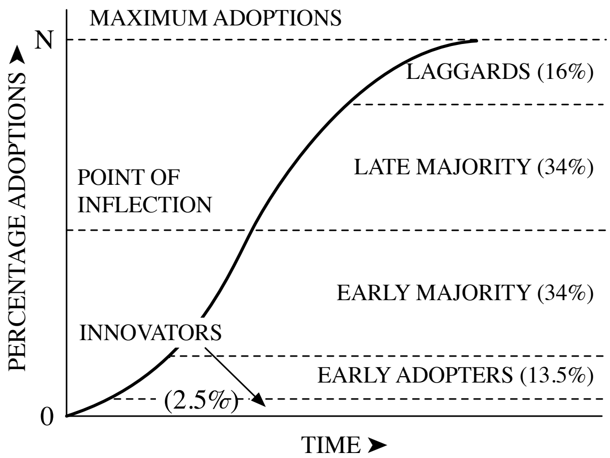


Figure 4: S-shaped growth as described in Rogers (2003)

Discontinuance is the decision to reject an innovation after initially adopting it. Leuthold (1967) argues that the discontinuance by different actors of an innovation is just as important as adoption. Discontinuance requires intensive data collection and is much harder to measure than adoption, as there are no readily available analogous statistical measures to collect data easily, like sales. As a result, discontinuance in many situations is hard to quantify, even though understanding reasons for discontinuance can be a valuable resource for product development.

Eysenbach (2005) uses the "law of attrition" to describe the discontinuance phenomena. It horizontally mirrors the S-shaped growth shown in Figure 3, until such a time where only 'hardcore' users are left. Increasing the hardcore user group is key to reducing disuse. If reasons for attrition can be measured or determined, it can provide feedback for improving the adoption process.

Reasons for Discontinuance

A major finding from the WSP field note (2007) is that filter disuse rate is approximately 2% per month, as shown graphically in Figure 1. Disuse is categorised into six reasons, as shown in Table 1.

Table 1: Surveyed Reasons for Disuse (WSP 2007)

Reason	Percentage
Broken (element, tap, or container)	65
Passed its 2-year lifespan	5
Cannot meet water demand	5
Water is 'already clean'	3
Gave filter to another household	3
Other Reasons	19

In the survey, no data was collected accounting for the type of CWF breakage, so it is unknown whether there is a weakness in the design of the CWF or associated plastics. Further, it is unknown how the break took place – whether it was due to a defect or misadventure. Inspection after breakage was difficult, as the CWF was often discarded after disuse: it is unknown whether breakage was the actual reason (WSP 2007). Understanding the reason for breakage could help target a design approach to address the breakage problem. A new design was considered outside the scope of this research, but as it is the prominent reason for discontinuance, it provides insight into how the transfer process could be improved.

Application of a Dynamical Approach
One final note of background is the work by Ngai and Fenner (2008). System dynamics is a business and management tool used to breakdown a complicated system with multiple inputs and feedback loops. Ngai and Fenner have applied this theory generally to the use of ceramic filtration and propose it as a simple method of understanding the system. This behaviour is shown in Figure 6b and compared to the data from this case study. When this model is simulated, current adopters can be measured against potential adopters and the discontinued population.

EVALUATION OF HYPOTHESIS

Hypothesis 1: CWF disuse is not linear
As shown in Figure 1, disuse over time is apparent. Figure 1, however, is somewhat misleading in Brown (2007) and WSP (2007). The graph shows that the odds-ratio for a filter being in use reduces at by 2% per month from an initial intervention.

However, in a dynamic, real-life situation the users do not exist in isolation. When considering discontinuance, the number of current users is of interest, as distinct from the percentage of filters in use. This is best shown using Eysenbach's (2005) model: the reverse S-shaped growth described in the previous section. Using the data from Brown (2007), the graph in Figure 5 was plotted.

By applying Eysenbach's understanding, a further observation arises for discussion. For there to be a sufficient 'curiosity' phase, a portion of the initial current users must be non-adopters. That is, these users never had the intention to adopt. This may be due to receiving the CWF for little or no investment under the WSP (2007). These users should be considered as a separate group. This observation is rarely considered in modern diffusion theory, and provides an opportunity for further research.

It should be noted that this data is not an ideal set for discontinuance, as it is based on a retrospective time since filter manufacture, rather than a continual survey of filters in use; however, it does present an alternative trend. Any further survey should consider this data need.

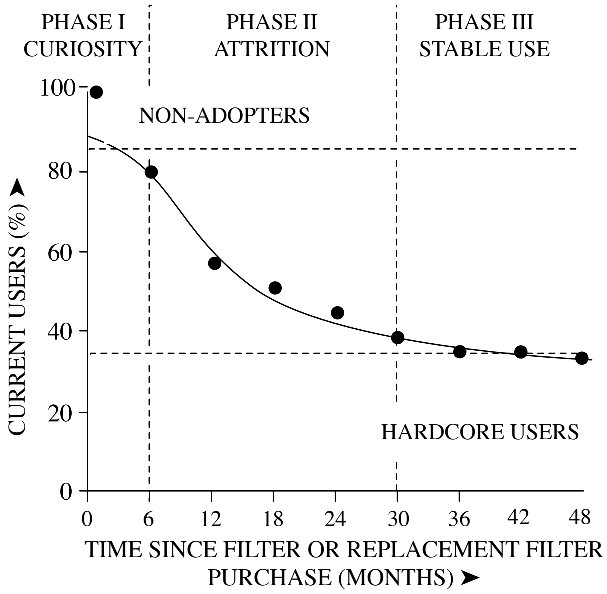


Figure 5: Discontinuance expressed in terms of current users (from data in Brown 2007).

Although it has been argued that Hypothesis 1 holds, more information about the data could elicit a deeper understanding of behaviour. The following information could provide greater insight if a follow-up survey were to be undertaken:

1. Seasonal production availability may influence the choice to discontinue through extended drying times in the wet season or ability to produce replacements.
2. Seasonal adoption and discontinuance may vary due to the shift in water sources and qualities shown in Figure 3.
3. The data considers CWFs in use and not the number of replacement filter elements. Given that the recommended life-span is 24 months, it can be assumed that users after 24 months have replaced their filter elements, though it is unknown.
4. The data does not account for purchase prices. It may be that the discontinuing users received the filter for a small investment, although it is unknown.

This understanding shows that it is reasonable to consider Hypothesis 1 as a likely assertion. Hence, Hypotheses 2 and 3 can be considered in the framework of diffusion theory.

Hypothesis 2: Maintenance can reduce disuse
As described in Ngai and Fenner (2008), adoption of ceramic filters can be shown in a system dynamics framework. This model is based on a classical logistic growth model which is explained in great detail in Sterman (2000). However, to use Ngai and Fenner's model in this case study, the adopters at each stage (potential, current and discontinued) should be considered as three categories:

1. *Intervention Adopters*
   These are the adopters whom never chose to use the innovation described in Figure 5.
2. *Organisational Adopters*
   This is part of the RDIC strategy to provide the innovation to schools and government departments. These adopters expose the innovation to a wide audience as described in WSP (2007).
3. *Consumer Adopters*
   These adopters are considered to exhibit typical adoption behaviour.

These have been combined in Figure 6a to simplify the figure. A further modification has been made to Ngai and Fenner's model, in that there exists initial adoptions at time 0 due to the rapid deployment of the intervention. Typical diffusion would have percentage adoption at t=0 as 0%, whereas this has been estimated to be 20%.

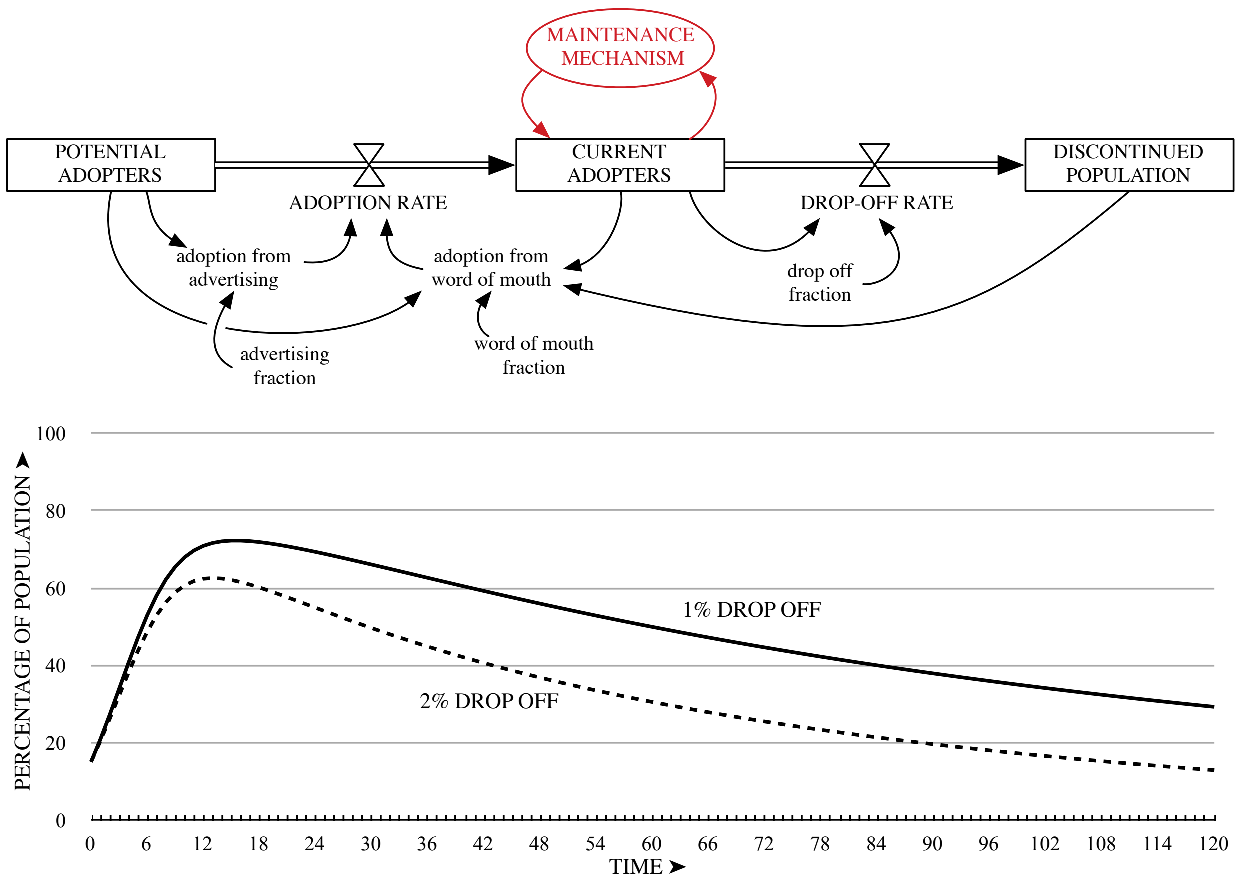
It is unknown what the maintenance mechanism in Figure 6a would look like. The term 'maintenance' refers to a maintaining of current adopter population, rather than a maintenance program on the filters, although it is likely that the former could be achieved through the latter. As shown in Figure 6b, if this maintenance mechanism could reduce the drop-off rate to 1% per month, approximately 15% more users would be using the innovation after the first year in the 10-year simulation.

Not only does this represent a significant improvement, it also represents an opportunity for RDIC to provide more replacement filter units – a 63% increase – given the recommended life-span of the filter unit is 24 months, shown in Table 2.

Table 2: Potential replacement units

Replacement filters opportunity at time	1% Drop-Off (units)	2% Drop-Off (units)
24 months	69	55
48 months	56	37
72 months	45	25
96 months	36	18
120 months	29	13
TOTAL	**235**	**148**

By developing the system dynamics framework of Ngai and Fenner, it has been shown that an opportunity exists to maintain the current users. Reducing the drop-off rate also offers significant opportunity for the producers of the filter to sell a greater number of replacement filters and further opportunity to encourage continued use.



Top - Figure 6a: Ngai and Fenner's (2007) model with the addition of a 'Maintenance Mechanism' in red to reinforce usage behaviour with current adopters. Bottom - Figure 6b: The long-term effectiveness of improving the disuse rate from 2% per month to 1% per month.

Hypothesis 3: A service model can reduce disuse

When a user chooses to discontinue using an innovation, there are two primary reasons for this behaviour: the user is either disenchanted with the innovation and reverts to prior practice or the user chooses to replace the innovation with a more appropriate technology. For the users of the CWF, the reasons provided in Table 1 tend towards disenchantment; there is no more appropriate technology available. Users tend to revert to boiling water or no filtration whatsoever. Hence, it is in the best interests of all parties that users do not discontinue using the CWF. A further finding of the WSP survey (2007) is that one-quarter of participants know how to purchase parts for the filter. This provides an opportunity and incentive for RDIC to improve the distribution of the CWF.

The approach undertaken by RDIC to distribute the innovation is as a discrete product sold in units, rather than as a continuous service. I assert that the transfer process could be improved if the approach to distributing the filters was reversed. By replacing the CF on a regular basis for a small maintenance fee, usage of the CWF innovation is reinforced.

This model is being used in a similar fashion in another industry in Cambodia: mobile phone technology. There are generally two methods of paying for a mobile phone: upfront, with a month-to-month service fee, or; on contract, with low upfront cost, on an increased-cost fixed-month contract. Sok (2005) observes that [urban] Cambodians prefer the first option: owning the technology, and paying a month-to-month service fee. I propose that usage of the CWF would be improved if it was approached in a similar manner. The CWF can be largely paid for upfront, and a replacement filter could be provided on a month-to-month basis for a small fee.

In this section, the hypotheses were evaluated. By exploring these hypotheses, discussion around the form and shape of any framework for upscaling can be undertaken.

DISCUSSION

In the *Contextual Background*, reference was made to the levels of technology transfer: technology development, technology acceptance, and technology application. Considering this, and the concepts from diffusion theory outlined in the previous section, recommendations for practical methods to reduce discontinuance can be made. These recommendations are not exclusive or ranked, and could be adopted in a flexible manner.

Level I: Technology Development Aspects

1. *Filters that are ready for use out of the box*

Colloidal silver is applied to the filter at the factory as a disinfectant. This application induces silver leaching, which creates a metallic taste. To counter this, instructions require the user to fill the filter twice before usage, which is approximately 10 hours of use. This places an unnecessary burden on the user, and failure to follow the instruction leaves the user dissatisfied. By shifting the burden of this instruction to the manufacturer, the user will be less likely to discontinue using the CWF.

2. *Pre-made screen to strain dirty water integrated into the design*

To reduce the amount of environmental debris, it is suggested that a screen is incorporated into the design. This is shown in Figure 7.

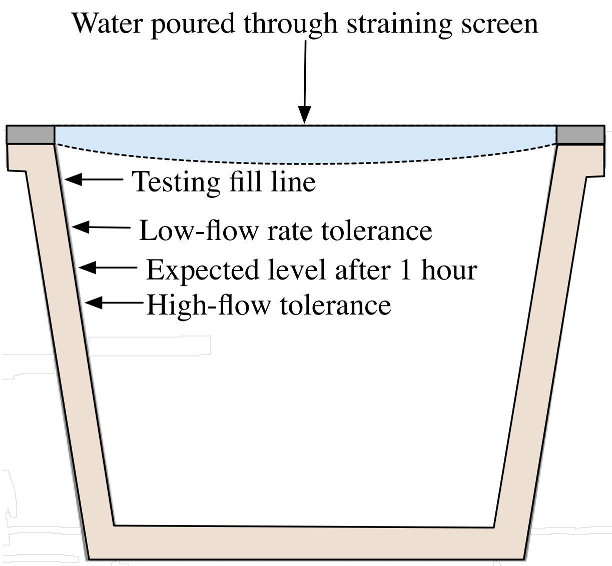


Figure 7: Visualisation of location of the straining screen and potential schema for the location of fill rates and indicators.

3. *Defined flow rate indication*

The manufacturer instructs that cleaning should take place when the flow rate becomes ‘slow’. Indicators on the side of the ceramic filter could help the user establish this objectively.

4. *Product differentiation*

The ceramic filter element has undergone various iterations in manufacturing process which has resulted in various filtration properties. By making the filter models clearly identifiable, the user will be better able to decide whether a replacement is warranted. This could be done through coloured markers or similar.

Level II: Technology Acceptance Aspects

At Level II and III, recommendations may be best fulfilled by a new service focussed on ensuring that filters in use are fit for purpose, rather than the householder.

1. *More complete instructions provided at the PoS, including a logbook*

A logbook-style record for the filter could help users identify when a new or replacement filter element is required.

2. *Training and demonstration sessions, including certification*

Training and demonstration of how filters are used and cleaned can help spread awareness of how to use the device, and help reduce disuse.

3. *On-site installation service*

A trained technician can help the householder identify the best location for the filter to avoid contamination, such as from animals licking the faucet. This also provides the opportunity for the householder to ask any questions.

Level III: Technology Application Aspects

1. *Authorised maintenance*

An authorised maintenance program could allow local experts to monitor the status of the ceramic filter and its use. This can help identify potential problems and encourage continued use.

2. *Regular certification that the filter is fit for use*

As part of authorised maintenance, a certification program could ensure that filters are 'fit for use'.

3. *A trade-in scheme to incentivise replacement*

Users should be able to access a trade-in scheme to reduce the cost of capital investment and encourage continued use.

Confluence of Transfer Aspects

As more ceramic filters are made for market, RDIC lose control of the innovation. This becomes a problem as the innovation moves into disuse: disused and broken filters are lost to the system.

In any effort to upscale, the innovation should remain the property of the manufacturer and the manufacturer should have a fundamental interest in ensuring that the innovation is working wherever it is installed. The CWFs should be regarded as a continuous *service*, rather than a discrete product.

A scheme whereby the recommendations provided are included to ensure maximum usage could be as described in Figure 8. No detailed costings have been undertaken for the elements, but any scheme developed further should be comparable to current costs. It is also anticipated that a higher usage rate will ensure that economies of scale will be able to be reached.

CONCLUSION

This paper proposed to evaluate three hypotheses. Hypothesis I evaluated whether the data from the WSP (2007) survey could be considered in diffusion theory. It established that this assertion held, and also asserts that a new group of users exist in the diffusion of innovations, coined *intervention* users, based on discontinuance. It was shown that these users appear to be a cross-section of the entire population, including approximately 15% of non-adopters. 35% of intervention adopters appear to be 'hardcore' users, which is an extremely positive indication.

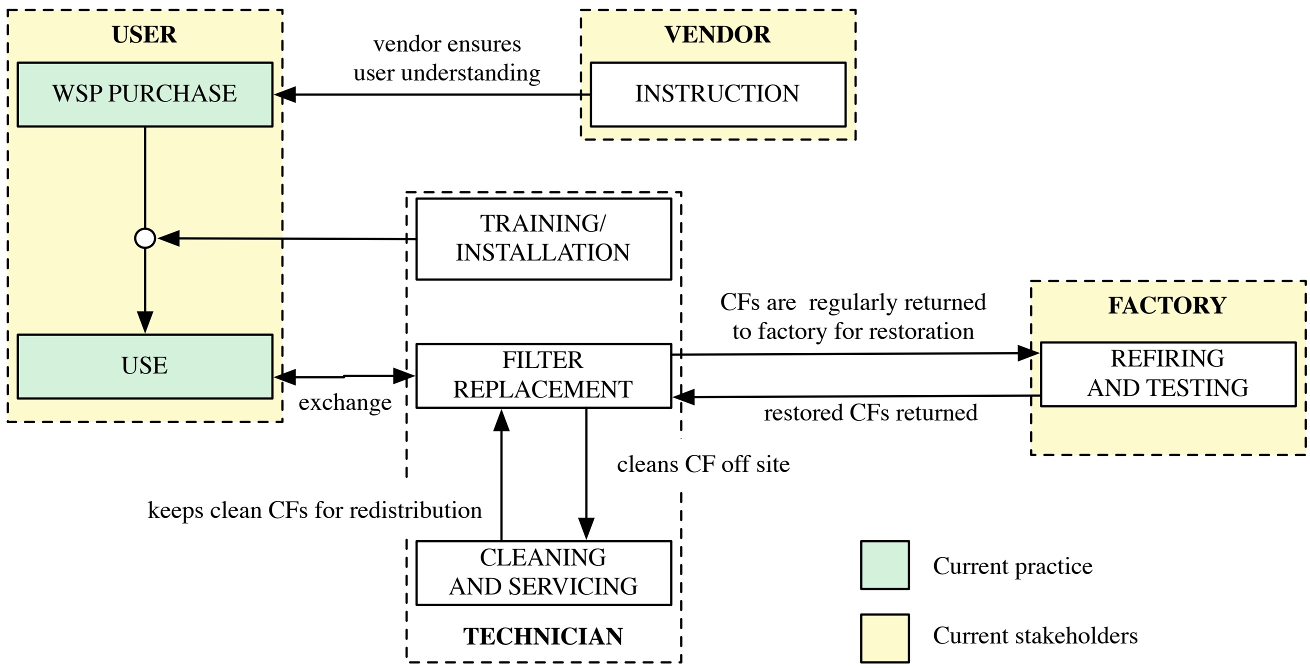


Figure 8: Mechanism to reduce discontinuance by providing the CWF as a behaviour-reinforcing service

The effect of a mechanism to reduce discontinuance was evaluated using systems dynamics in hypothesis II. This evaluation showed that significant improvements could be made to the levels of current adopters by employing a mechanism to reinforce usage.

Hypothesis III was explored and suggestions were put forward for a CWF service model. This hypothesis was unable to be evaluated against existing innovations, but evidence suggests that Cambodians currently adopt innovations such as mobile phones in this way.

By reducing discontinuance and reinforcing usage through a service model, the health benefits of the CWF will have a greater reach within the societal system.

FURTHER RESEARCH

As the participatory development theory suggests, a consultative approach is required to determine whether the service model could be applied to the situation. Although the preliminary research in this thesis shows that Hypothesis III has potential, it remains to be proven, and could be the topic of a higher-level dissertation.

In addition, further research opportunities exist in the areas of:

- Improving filter design for portability and robustness
- Improving the strength of the ceramic filters
- Applying silver colloid before the firing process
- Improving flow rates by roughening the surface finish (sanding to expose voids)
- On-the-spot water testing technology
- Reusing material from broken filters as a grog

ACKNOWLEDGEMENTS

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This paper is based on a final-year Engineering thesis, which also details experimental results for the benefits of refiring ceramics clogged with organic matter. For further information on this project, please contact the author.

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