Innovative Design of Latex Gloves Production Lines via Modular Industrial-sized Prototypes

P Yongyingsakthavorn¹, T Chantrasmi, T Srijubol, P Nimdum, A Tohsan and U Nontakaew

¹ Development of Machinery and Industrial Equipment Research Center (DMIE), and Faculty of Engineering, King Mongkut’s University of Technology North Bangkok, 1518 Pracharat 1 Rd., Bangsue, Bangkok, 10800 THAILAND

*Corresponding author: pisit.y@eng.kmutnb.ac.th

Abstract. An innovative design of continuous latex gloves production lines was introduced in work. A modular approach to the designing process was described and key technologies were identified. Based on these technologies, industrial-sized prototypes were constructed and tested. The objectives were largely to reduce the production cost by some means such as reducing the thermal energy usage, shortening the length production line and time and decreasing the number of stationed workers. As a proof of concepts, prototypes of drying oven and stripping machine were constructed and the vulcanization experiments were carried out. The results were promising, for instances, the new drying oven with outside chain was projected to be able to reduce the thermal energy loss by approximately 12% compared to the traditional design and the stripping machine was shown to be able to vertically remove latex gloves from formers while occupying less space and potentially using fewer workers. From the vulcanization experiment, it was shown that the vulcanization time could be significantly shortened by pre-vulcanization and drying process.

1. Background and Introduction

Latex medical gloves industry has been growing continuously in Thailand, the largest manufacturer and exporter of raw-material rubber with one third of the total exports in the world. The demand for latex gloves worldwide rises an average of 5-10% per year or roughly 1,000 million pairs per year [1]. Meanwhile, it has been found that several Thai gloves manufacturers face many problems, such as higher production cost, both in term of materials and energy usage as well as from inefficiently old technologies.

To achieve competitiveness, our researchers and engineers are working to improve the production process starting from conceptual design, detailed design, manufacturing and finally testing. Many researchers were focusing on the chemical aspects of the process such as finding new latex formula and the effect of filling to reduce the material cost [2]. Little attention had been paid to the mechanical aspect of the production lines. In this work, the emphasis was on the mechanical aspect, particularly to find innovative solutions to improve each module of the powder-free production lines. As a constraint, the new solutions must be capable of producing at least 1 million pieces/day (42,000 pieces/hr).
The researchers have defined six key modules, namely stable conveying system, effective stripping and counting, latex dipping, former cleaning, drying and vulcanization. Currently, three out of the six – drying, stripping and vulcanization – were selected for detailed scrutiny and practical verification. In this phase, modular industrial-sized prototypes were to be fabricated as proofs of concept. The content below is divided into four more sections. The first three were organized according to the selected modules and the last section was the concluding remarks.

2. Drying and Vulcanization Ovens

One of the key modules to reduce the production cost by energy usage reduction is drying and vulcanization as discussed above. In the process of drying and vulcanization, a number of heated ovens are typically employed throughout the production line. These ovens operate in the temperature range of 90-130°C [3] and can be quite humid inside due to the trapped water vapor from the formers.

Theoretically, the heat energy required – to raise the temperature of and evaporate the liquid water on the various stages of in-the-making latex gloves as well as on the former surfaces – is very small but there is usually a huge energy loss in the system.

Besides traditionally considered forms of heat loss through the insulated oven walls and convectively through hot air leakage, it has been identified that energy loss due to the conveyor chain plays a very significant role [4]. The conveyor chain – as well as additional pieces connecting the moving chain to the formers – is made of metal and thus can store a large amount of heat energy while it remains inside a heated oven. Once it emerges, it has a higher temperature than its surroundings (i.e. air at around room temperature) and therefore releases the stored heat energy back outside the oven, resulting in the energy loss. This is the so-called convective heat transfer by the conveyor chain in which the solid chain acts as a moving carrier of the thermal energy – as opposed to a conductive loss mode where heat is conducted along the length of the chain from inside to outside of the oven.

In this innovative design of the ovens, our researchers and engineers design an oven with outside conveyor chain as to avoid the above-mentioned heat loss. Figure 1 shows a traditional oven with inside conveyor chain. The innovative oven is divided into two parts with smaller drying volume so that the conveyor chain is arranged outside. Although it is clear by design that this will drastically reduce the convective heat loss, the new design also features more wall surface area and possibly more air leakage since, along the length of the conveyor chain, there is a long slot through which the connecting pieces between the chain and the formers move. As a result, heat loss through other modes might be increased. Therefore, at the conceptual level, it was not immediately clear whether the new design will result in energy saving in an actual practice. An industrial-sized prototype of this design is then constructed to collect data in order to answer this question.

![Figure 1. Schematic drawings of a traditional oven](image-url)
The experimental setup for industrial-sized prototype of this new oven design is established, the prototype features a 20-meter conveyor chain in a simple loop through with 12 meters of chain inside the oven. It is a stand-alone prototype completed with hot-air delivery system, conveyor chain driving system and automatic control with a touch-screen panel. The prototype was then built accordingly and testing data were collected. The results were analyzed and showed that it was structurally sound, it was concluded that the new design would save approximately 12% of energy in an example production line [5]. This quantitative calculation assumed that the ovens of this type were to replace all the existing ovens in the production line. This would result an overall reduction of conveyor chain temperature everywhere (in other modules as well). A simple theoretical model was used to predict this new temperature profile and the quoted 12% saving was then based on this model [5]. Note that if this theoretical model was not used and the temperature of the chain was the same as with the traditional ovens, the energy saving would be well over-estimated.

3. Stripping Machine
Another identified key module essential to the innovative design is the stripping module. As the module’s objectives, the new design must be (i) able to change its pitch distance to synchronize with the conveyor chain’s pitch that changes slowly over time, (ii) able to reduce the required space both lengths wise an span wise, and (iii) easy to combine with the counting and packaging modules so as to reduce the number of stationed workers required, thus saving the production cost. The prototype is capable of vertically stripping formers from a double-former production line, meets the above objectives and is functionally equivalent to four conventional (horizontal) stripping machines commercially available in market.

4. Vulcanization
Generally, vulcanization of latex gloves consists of three main processes, which are pre-vulcanization (maturation), drying and curing. In order to shorten the vulcanization time of latex gloves, the pre-vulcanization and drying processes were focused in the present work. First, an effect of pre-vulcanization time was evaluated by using swelling test as shown results in Figure 2 (a). It was observed that percentage of total solid content (% TSC) has no effect on pre-vulcanization time, i.e., equilibrium state was reached after 24 hours. In the case of filled sample, the pre-vulcanization time was reached after 36 hours. This result suggested that the presence of filler tends to prevent the pre-vulcanization of latex compound. Practically, in the production line, the pre-vulcanization is set at 60-80 hours. Therefore, from this experimental results, it may suggest that the pre-vulcanization time can be approximately decreased into 50% shorter.

In term of drying, evaporation flux of water in the latex film was calculated [6]. The obtained results are shown in Figure 2 (b). A similar tendency with swelling results was observed. It was found that % TSC has no effect on evaporation flux, i.e., the drying was completed after 5 min. In the case of filled latex film, the drying was extended to 7.5 min which is 50% shorter than the drying time that use in the production line.
5. Conclusions
A modular approach to the designing process was described and key technologies were identified. Industrial-sized prototypes of drying oven and stripping machine were constructed and tested. They showed that the production cost could be potentially reduced by employing these new designs. The new drying oven has the conveyor chain outside the heated oven area and was projected to reduce the total energy loss by approximately 12% on an example production line. The stripping machine could vertically strip latex gloves out of formers while demonstrably occupying less space and thus potentially using fewer stationed workers. The results from the vulcanization experiment showed that the required time could be significantly shortened by 50% via pre-vulcanization and drying process.

6. References
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